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RADC NONELECTRONIC RELIABILITY NOTEBOOK

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Hughes Aircraft Company

Ray E. Schafer, John E. Angus, Jack M. Finkelstein, Mal Yerasi/
Hughes Aircraft Company, and Donald W. Fulton/Reliability
Analysis Center (IITRI)

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APPROVED:

JAMES A. COLLINS
Project Engineer

APPROVED:

W. S. TUTHILL, Colonel, USAF
Chief, Reliability & Compatibility Division

FOR THE COMMANDER:

JOHN A. RITZ
Acting Chief, Plans Office

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The objective of this Notebook was the collection, analysis, and presentation of nonelectronic component failure data and the presentation of analytical methods that form the state-of-the-art in nonelectronic reliability analysis. This report replaces the former Nonelectronic Reliability Notebook (RADC-TR-75-22). Topics include:

This notebook is divided into six sections: Introduction, Applicable Statistical Methods for Nonelectronic Reliability; Reliability Specifications; Special Application Methods for Reliability Prediction; Part Failure Characteristics; and Reliability Demonstration Tests. ... between failures;

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22a. NAME OF RESPONSIBLE INDIVIDUAL
JAMES A. COLLINS

22b. TELEPHONE *(Include Area Code)*
(315) 330-2101

22c. OFFICE SYMBOL
RADC (RBES)

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PREFACE

This Notebook is the result of research conducted at Hughes Aircraft Company, Ground Systems Group, Fullerton, California, for Rome Air Development Center under contract number F30602-82-C-0127, covering the period July 1982 through August 1985. The RADC project engineer for this effort was Mr. James A. Collins (RADC/RBES). This research was undertaken within the Systems Projects Section of the Systems Effectiveness Department of Hughes under the direction and supervision of Dr. Ray E. Schafer until his untimely death in September 1983. At that time, direction of the research was taken over by Dr. John E. Angus with support and assistance from Mr. Tom F. Pliska, Systems Effectiveness Department Assistant Manager, and Mr. Larry E. James, Systems Projects Section Head.

Several individuals made significant technical contributions to this research. Dr. Mal Yerasi, working closely with Dr. Schafer, collected and compiled the entire database of nonelectronic part failure data. The statistical analyses and report generation for the Part Failure Characteristics Section of the Notebook was undertaken by Dr. Angus with extensive computer programming support from Mr. Shick P. Jue. Under a subcontract, Mr. Donald W. Fulton of RAC/IITRI (and past Rome project engineer on a previous edition of this Notebook) wrote the section on Special Application Methods for Reliability Prediction. Finally, the sections on Reliability Demonstration and Specification were written by Dr. Angus with assistance from Mr. Jack M. Finkelstein who also reviewed the entire Notebook. The Hughes report number for this document is FR84-16-446 Rev B.

This document replaces RADC-TR-75-22, Nonelectronic Reliability Notebook. Although RADC's interest in nonelectronic/mechanical components is limited to those used in electronic systems, this revised Notebook contains failure data and reliability methods pertaining to a variety of applications.

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1.0 INTRODUCTION

The purpose of the RADC Nonelectronic Reliability Notebook is twofold. First, it serves as a reference document for the reliability characteristics of the most commonly used, nonelectronic parts based on industry supplied failure data; and secondly, to present the most useful reliability and life data analysis methods applicable to nonelectronic parts. These analysis methods are presented without regard to rigorous mathematical derivation and with an emphasis on making them accessible to reliability practitioners possessing moderate statistical/mathematical training.

The suggested use of this Notebook is described by the table below where each reliability task is associated with a section of this Notebook. The use of section 5.0, Part Failure Characteristics, requires some elaboration. In the majority of cases, the nonelectronic parts covered in this Notebook are adequately described in the reliability sense by a constant failure rate. Thus, mainly, section 5.0 will be used to look up a failure rate for a particular device. Sometimes, however, either the part will exhibit nonconstant failure rate, or the analyst will simply wish to use a Weibull analysis of the part's reliability characteristics. For these purposes, section 5.0 also presents Weibull analyses for selected nonelectronic parts based on the availability of actual failure times in the database. These Weibull analyses are based on data from three different projects, two in the ground mobile application environment, and one in the ground fixed environment. In many cases, the same part type occurs in more than one Weibull analysis. In these cases, if it is desired to use the Weibull analysis for modeling, the analysis in which the most failures were recorded should be used. In some instances, the estimated parameters in the Weibull analyses of the same part type will differ greatly. These differences are explained by differences between project applications (even though the projects have the same use environment) of the parts, and differences between parts of the same name and type due to lack of data which would better characterize the parts (i.e., two parts of the same generic part name and type can be, nevertheless, different). As the results of these analyses indicate the vast majority of the time, the constant failure rate tables will be adequate. In spite of this result, the Weibull analyses have been included for reference.

Reliability Task	Nonelectronic Reliability Notebook Sections(s)
Specification	Section 3.0
Prediction	Section 5.0, if part is represented there; Section 2.0, if failure data is available; Section 4.0, if no failure data is available.
Demonstration	Section 6.0

Section 2.0 of this Notebook describes the selection and application of several failure distributions which are used for describing the life characteristics of nonelectronic parts, given part failure data. The remainder of this section is devoted to methods of operating on failure data once a failure distribution has been found to, or is assumed to, describe nonelectronic part failure times. The general format used includes methods of point and interval estimation for the reliability parameters of the proven or assumed failure distribution based on empirical data.

Section 3.0 of this notebook presents guidelines and criteria for specifying reliability for nonelectronic parts and equipments. Specifications appropriate for the nonparametric reliability demonstration test plans presented in section 6.0 are included.

The next section of the notebook, section 4.0, addresses reliability prediction, and is intended to supplement section 5.0. It gives rules for using specific prediction models which are known to have application to certain nonelectronic parts. This section is oriented towards strength of alloys, grease and oil lubricated rolling bearings, and spur gear systems. It explains and gives examples on the use of stress-strength interference theory. A new subsection addressing reliability prediction based on minimal vendor information and no life data is also included.

Section 5.0 is Part Failure Characteristics. This section describes the results of the statistical analyses of failure data from more than 250 distinct nonelectronic parts collected from recent commercial and military projects. This data was collected in-house (from operations and maintenance reports) and from industry wide sources, all of whom are aware of the importance of this Notebook. Tables, alphabetized by part class/part type, are presented for easy reference to part failure rates assuming that the part lives are exponentially distributed (as in previous editions of this notebook, the majority of data available included total operating time, and total number of failures only). For parts for which the actual life times for each part under test were included in the database, further tables are presented which describe the results of testing the fit of the exponential and Weibull distributions. A quick reference index for locating the beginning page of the Tables for each part class is presented in Table 1.1 in this introduction. The results show that the exponential distribution is adequate for a large majority of the nonelectronic parts for which its fit was tested. A small number of nonelectronic parts exhibited life times which were better described by the Weibull distribution. Recommendations for approximating these cases by the exponential distribution are presented. Part malfunction data which was available when the part failure data was collected is presented in Table 5.6.1. See the contract Final Technical Report describing the study and investigation for more details on data and data analysis (RADC-TR-85-66 dated April 1985, AD A157242).

Section 6.0 presents reliabilty demonstration test plans applicable to nonelectronic parts. Both attributes and variables types of demonstration plans are described. <u>Attributes</u> plans are used to demonstate whether

or not a finite population of items possesses an acceptable fraction of items which have a particular attribute, while variables plans are used to demonstrate whether or not a particular type of item possesses an acceptable level of some pre-specified reliability quantity. Whenever the exponential distribution is judged appropriate for the life distribution of an item of interest, test plans are documented in Mil-STD-781C and Mil-HDBK-108 and are not reproduced in this section. When the exponential distribution is not appropriate, the variables test plans of this section are nonparametric (i.e., not dependent on the form of the underlying life distribution) and based on one dimensional reliability specifications. Because of this, these test plans are easy to design and use, and operating characteristic curves can be developed and used.

TABLE 1.1

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*NOTE: A listing under this column indicates that a Weibull analysis for one or more part types and environments under this part class is included in Sections 5.3 - 5.5.

PART CLASS	PAGE NO. EXPONENTIAL DIST	*PAGE NO. WEIBULL DIST
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*NOTE: A listing under this column indicates that a Weibull analysis for one or more part types and environments under this part class is included in Sections 5.3 - 5.5.

PART CLASS	PAGE NO. EXPONENTIAL DIST	*PAGE NO. WEIBULL DIST
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*NOTE: A listing under this column indicates that a Weibull analysis for one or more part types and environments under this part class is included in Sections 5.3 - 5.5.

PART CLASS	PAGE NO. EXPONENTIAL DIST	*PAGE NO. WEIBULL DIST
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*NOTE: A listing under this column indicates that a Weibull analysis for one or more part types and environments under this part class is included in Sections 5.3 - 5.5.

2.0 APPLICABLE STATISTICAL METHODS FOR NONELECTRONIC RELIABILITY*

2.1 Statistical Failure Models.

2.1.1 The Hazard Rate Concept. The measure of an equipment's reliability is the infrequency with which failures occur in time. A failure distribution represents an attempt to describe mathematically the length of life of a material, a structure, or a device. There are many physical causes that individually or collectively may be responsible for the failure of a device at any particular instant. The present state-of-the-art does not permit isolation of these physical causes and mathematical account for all of them, and, as a consequence, the choice of a failure distribution is still an art. If one tries to rely on actual observations of time to failure to distinguish among the various nonsymmetrical probability functions, one is still faced with a difficulty because nonsymmetric distributions are significantly different at the tails and actual observations are sparse, particularly at the right-hand tail, because of limited sample size.

In view of these difficulties, it is often necessary to hypothesize the type of failure distribution on the basis of knowledge of the physical failure process. For example, fatigue failure of nonelectronic parts is usually assumed to follow a Weibull probability distribution because the theoretical development of this distribution was based on fatigue type failures.

One useful characteristic of failure distributions is the hazard rate or failure rate.

$$\text{Hazard rate, } h(x) = \frac{f(x)}{1-F(x)}$$

where $f(x)$ = density function

$1-F(x)$ = reliability.

Hazard rate is the probability that a device already in service for time x, will fail in the next instant of time, given no failure up to x.

Each absolutely continuous probability distribution can be characterized by the hazard rate. Physical systems can also be classified in the same manner. Thus the nature of the failure rates in a physical system suggests the type of probability distribution to be assumed.

*This entire section has been reprinted (with minor corrections) from RADC-TR-75-22. A revised statistical methods section containing additional advanced methods was done and is included as Appendix III of the Final Report describing the study and investigation (RADC-TR-85-66).

To assist the choice of $h(x)$ three types of failures generally have been recognized as having a time characteristic. The first one, called the initial failure, manifests itself shortly after time $x = 0$. The frequency of failures of this type decreases during the initial period of operation. A good example of this is the standard human mortality table, in which it is assumed that up to the age of 10 years a child can die of hereditary defects, but having lived past this age, it is almost free of such defects. The second type occurs during the "chance failure period," in which the device exhibits a constant failure rate, generally lower than during the initial period. The cause of this failure is attributed to unusually severe and unpredictable environmental conditions occurring during the operating time of the device. In the example of human mortality tables, it is assumed that deaths between the ages of 10 and 30 years are generally due to accidents. The third type is called the wearout failure period, and is associated with the gradual depletion of a material, or an accumulation of shocks, fatigue, and so on. In the human mortality tables discussed before, after an age of 30 years an increasing proportion of deaths are attributed to "old age." The three types of failures have been classically represented by the "bathtub" curve, wherein each one of the three segments of the curve represents the three time periods of initial, chance, and wearout.

The discussion in the previous paragraphs applies to the theory of life testing in general and may not apply strictly to every case where the life characteristics of nonelectronic parts are involved. For example the wearout process begins immediately in many types of nonelectronic parts.

It was stated before that given the functional form of $h(x)$, the density function $f(x)$ and the cumulative distribution function $F(x)$ could be easily determined. The development of the following two results is straightforward and can be found in Barlow and Proschan (1964).

$$1 - F(x) = \exp\left(-\int_0^x h(x)dx\right) \tag{2.1.1}$$

and

$$f(x) = h(x)\exp\left(-\int_0^x h(x)dx\right). \tag{2.1.2}$$

In the sections to follow a use will be made of this technique to develop the commonly used failure distributions.

2.1.2 <u>The Poisson Process and the Exponential Distribution</u>. In reliability studies, the exponential distribution plays a role analogous to that of the normal distribution in other areas of statistics. An acceptable justification for the assumption of an exponential distribution to life

studies was initially discussed by Epstein in 1953. More recently a mathematical argument has been advanced to support the plausibility of the exponential as the failure law of complex equipment (Barlow & Proschan, 1964, p. 18). Although many life distributions, especially those pertaining to the nonelectronic devices, cannot be adequately described by the exponential distribution, an understanding of the theory in the exponential case facilitates the treatment of the more general cases. The desirability of the exponential distribution is because of its simplicity and its inherent association with the well developed theory of Poisson Processes (Feller, 1968). The applicability of the exponential distribution is limited because of its lack of memory property; this property requires that the previous use does not affect its future life length, and the exponential distribution is the only continuous distribution with this property (Feller, 1968).

2.1.2.1 The Poisson Process. The exponential distribution corresponds to a purely random failure pattern, and mathematically this means that whatever is causing the failure occurs according to a Poisson Process with some parameter λ. The Poisson probability law can be derived from rigorous mathematical considerations, and the interested reader is referred to Feller (1968). Briefly, the postulates of a Poisson Process are stated below.

Consider a system (or a unit) subjected to instantaneous changes due to the occurrence of random events (shocks). All random events are assumed to be of the same kind, and one is interested in their total number. Let $P_m(t)$ be the probability that exactly m random events occur during a time interval of length t.

The physical process that induces the occurrence of the random events is characterized by the following two postulates:

i) the process is time homogeneous and the future occurrences of the random event are independent of its past occurrences.

ii) the simultaneous occurrences of two or more events is excluded.

The above postulates lead to a system of differential equations for $P_m(t)$, which lead to

$$P_m(t) = \frac{e^{-\lambda t}(\lambda t)^m}{m!}, \quad m = 0, 1, 2, \ldots$$

2.1.2.2 The Exponential Distribution. The probability density function of the exponential distribution can be obtained from either the hazard rate concept, or by considering the waiting time between arrivals in a Poisson Process. Consider the latter situation first.

Suppose that the device under consideration is subjected to an environment in which shocks occur according to the Poisson distribution, with a Poisson rate λ. The device will fail only if a shock occurs and will not fail otherwise. Let X be the life of the device.

Let $R(x) = Pr(X > x) = Pr$ [no shocks occur during $(0,x)$]

$= e^{-\lambda x}$, by putting $m = 0$.

$Pr(X \leq x) = 1 - e^{-\lambda x}$ or

$$f(x) = \lambda e^{-\lambda x}, \qquad x \geq 0.$$

The same expression for the probability density function of X could be obtained from the hazard rate concept, since the assumption of random shocks with a constant Poisson rate λ implies a constant failure rate $h(x) = \lambda$, for $x \geq 0$.

Substituting $h(x) = \lambda$ in equations 2.1.1 and 2.1.2 one has

$$F(x) = 1 - e^{-\lambda x}.$$

This section will be concluded by emphasizing the fact that the exponential distribution can be chosen as a failure distribution if and only if the assumption of a constant hazard rate can be justified. This assumption implies that the failure of a device is not because of its deterioration due to wear, but is due to random shocks which occur according to the postulates of a Poisson Process. This fact is of importance in nonelectronic parts consideration, since invariably the failure of these is due to either a pure wear or due to a combination of wear and shocks.

2.1.3 The Weibull Distribution. Recently, the Weibull distribution has emerged to be a popular parametric family of failure distributions. Its applicability to a wide variety of failure situations was discussed by Weibull (1951); it has been used to describe vacuum tube failure by Kao (1958) and a ball bearing failure by Lieblein et. al. (1956). While the applicability of the exponential distribution in limited because of the assumption of a constant hazard rate, the family of Weibull distributions can be written to include the increasing and the decreasing hazard rates as well. Since many mechanical or electromechanical components have an increasing failure rate (i.e., due to deterioration or wear), the Weibull distribution is more palatable in describing the failure pattern of such devices.

If the hazard rate $h(x)$ is some monotone function of x, say if

$$h(x) = \frac{\beta}{\alpha}(x-\gamma)^{\beta-1}, \; \beta, \; \alpha > 0, \; \gamma \geq 0, \; x \geq \gamma$$

then equations 2.1.1, and 2.1.2 give

$$F(x) = 1 - \exp\left[-\frac{(x-\gamma)^{\beta}}{\alpha}\right] \text{ for } x \geq \gamma \text{ and}$$

$$f(x) = \frac{\beta}{\alpha}(x-\gamma)^{\beta-1} \exp\left[-\frac{(x-\gamma)^{\beta}}{\alpha}\right] \qquad \ldots\ldots\ x \geq \gamma$$

$$= 0 \text{ otherwise.}$$

β, α, and γ are the shape, the scale, and the location parameters respectively. In Section 5 of this notebook (and other sources) the scale parameter is $\alpha^{1/\beta}$.

The hazard rate for the Weibull distribution is increasing in $(x-\gamma)$ if $\beta > 1$, and is independent of x if $\beta = 1$. When $\beta = 1$, the Weibull distribution becomes the exponential distribution with location parameter γ, and when $\beta < 1$, the Weibull distribution reduces to what is called the hyper exponential distribution. When $\beta < 1$, the hazard rate decreases in $(x-\gamma)$, and such a hazard rate is useful in characterizing phenomenon such as work hardening or other phenomenon associated with the improvement of reliability such as debugging, etc.

Experience in the use of the Weibull distribution in describing the life characteristics of nonelectronic parts leads to the conclusion that very often the location parameter γ can be assumed to be zero. This leads to the failure model referred to in many of the methods presented in this and succeeding sections of this notebook as the two parameter Weibull distribution.

2.1.4 The Normal Distribution. A fundamental derivation of this distribution is not attempted here because of its familiarity.

If X denotes the time to failure random variable of a device which fails according to the normal or Gaussian law, then the probability density function of X is given by

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-1/2\left(\frac{x-\mu}{\sigma}\right)^2} \qquad -\infty < x < \infty.$$

μ and σ are the parameters, commonly referred to as the mean and the standard deviation respectively. The failure rate of the normal distribution is increasing in x, and hence, this distribution can be used to characterize wear. Since it is not possible to observe negative lifetimes, the use of this distribution is limited to positive random variables.

2.1.5 The Log-Normal Distribution. The Log-Normal Distribution can sometimes be used as a failure model when failure is due to fracture. Since failures due to fracture occur quite commonly in practice, especially for nonelectronic devices, a study of the Log-Normal Distribution is warranted.

The Log-Normal Distribution implies that the logarithms of the lifetimes are normally distributed, and hence, it can be easily derived by a simple logarithmic transformation. It can also be derived more fundamentally by considering a physical process wherein failure is due to fatigue cracks, and the interested reader is referred to Kao (1965). The probability density function of the Log-Normal Distribution is given by

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left\{- 1/2 \left(\frac{\log x-\mu}{\sigma}\right)^2\right\}, \quad x > 0,\ \sigma > 0,\ -\infty < \mu < \infty;$$

$$= 0 \text{ otherwise.}$$

μ and σ are the (usually) unknown parameters.

2.1.6 Extreme Value Distribution. The Largest Extreme Value (L.E.V.) distribution is a two parameter right-skewed probability distribution, similar in appearance to the gamma, log-normal, or Weibull distribution. The L.E.V. distribution has been successfully fitted to failure data, particularly where failures are caused by fluctuation of a random load variable such as stress or voltage. For example, a component with tensile strength Y is subjected to a stress during each mission. Let X be the largest stress observed in n missions. If n is large, the random variable, X, will have a L.E.V. distribution, and reliability for n missions will be given by $P(X < Y)$, assuming that the theory of cumulative damage does not apply.

The L.E.V. distribution reliability function is

$$R(x) = 1 - \exp\left(-e^{-b(x-m)}\right) \qquad b > 0, \qquad -\infty < x < \infty$$

and the density function is

$$f(x) = be^{-b(x-m)} \exp\left(-e^{-b(x-m)}\right).$$

The Smallest Extreme Value (S.E.V.) distribution is the "mirror image" of the L.E.V. distribution and represents the distribution of the smallest observation in a large number of trials. It is unique among the many life distributions available in that the probability distribution is skewed to the

left. One obvious application for the S.E.V. distribution is the "chain" model, a series system of n components where X is the lowest strength among the components. For large n, X has a S.E.V. distribution.

The reliability function is

$$R(x) = \exp\left(-e^{\beta(x-m)}\right) \qquad \beta > 0, \quad -\infty < x < \infty$$

and the density function

$$f(x) = \beta e^{\beta(x-m)} \exp\left(-e^{\beta(x-m)}\right) .$$

2.1.7 Summary. In the preceding sections several failure models were proposed as possible candidates for describing the life characteristics of nonelectronic parts. In practice, it is very difficult to identify a particular model as the suitable one, because of the considerations given in Section 2.1.1. However, some broad guidelines for the applicability of certain models were given in the other sections and these can be presented in the table below.

Model	Applicability Conditions	Comments
Exponential	Failure due to exactly 1 random shock Systems comprised of many components	Does not characterize wear
Weibull	Applicable under a variety of conditions, especially mechanical parts that fail due to wear	Characterizes wear or work hardening
Normal	Failures occur due to wearout	Describes many life processes as well as many manufacturing processes
Log-Normal	Failure due to fatigue cracks	Characterizes wear
Extreme Value	Failure due to extreme value of some variable	Corrosion is one example

The remainder of this section of the Notebook is devoted to methods of operating on failure data once one of the previously discussed failure distributions is found to or is assumed to describe nonelectronic part failure times. The section is divided by failure distribution and follows a similar pattern for each. Methods are described for calculating point estimates of the reliability or of other parameters of the proven or assumed failure distribution based on empirical data. Where they are available and have utility for the users of the Notebook, graphical methods for estimating these

same values are presented. The general format used includes methods of point and interval estimation for the reliability parameters of each failure distribution. Numerical examples are presented and the user of the Notebook is furnished with references for theoretical development and additional examples of each of the methods presented.

2.2 Design of Statistical Experiments.

2.2.1 Introduction. Since the state of the art of failure data collection for nonelectronic parts does not give sufficient information for proper analysis, it is necessary to generate the needed information in a systematic manner.

In collecting failure data for estimating reliability characteristics for nonelectronic parts, one is frequently faced with insufficient information. This problem arises from the manner in which the data is collected. It is common practice to include only the operating time of the equipments or systems and the number of failures observed during the operational period covered by a failure report. Individual part failure times are generally not recorded.

This section of the Notebook, therefore, is devoted to describing the methodology or the principles to be followed in the event that one has the opportunity to generate failure data for a nonelectronic part. It describes in a logical manner the discrete guidelines for setting up an experiment which will yield an evaluation of the important factors or combinations of factors which affect the life characteristics of the parts of interest.

The general steps for planning and conducting an experiment plus the procedures to be followed to most efficiently analyze the results of a test program for nonelectronic parts are outlined below. The remainder of this subsection describes these steps in detail and references sources which can be used as patterns to be followed in generating and analyzing the types of information which are required to allow a complete and detailed reliability analysis of nonelectronic parts and of the operating and environmental stresses which affect their life characteristics.

When these guidelines are utilized in the generation and analysis of reliability data for nonelectronic parts, a full and complete analysis of all the data should be possible and no assumptions or guesses should be required which might dilute the power of the conclusions that can be reached from a proper treatment of failure data.

The major steps discussed in the succeeding pages are:

1. Determination of Stresses
2. Determination of Stress Levels
3. Statistical Test Designs
4. Physical Test Designs
5. Analysis of Experimental Data

2.2.2 Determination of Stresses and Stress Levels. In setting up an experiment to generate reliability data on nonelectronic parts, those stresses should be evaluated which experience and/or failure mode analysis indicates have the greatest effect on part life for the applications of interest.

Even if a part is operated in a very benign environment, there are still many factors competing in combination to cause deterioration of its life characteristics. The rate of deterioration is a function of the level or concentration of a given stress. It is well-known that certain factors affect a product more than others. For example, a tire's life is reduced by vibration, radiation, corrosive agents, type of road surface, and temperature to name but a few factors. It is well-known, however, that the effects of temperature greatly exceed the effects of other environmental stresses to the point that setting up an experiment to evaluate the life characteristics of this part without including this factor would render useless or distorted results. Some factors work in combination in such a manner that their effect together is greater than the sum of their individual effects acting separately. For example, ozone increases the tendency of rubber to crack, but ozone combined with high temperature creates an even greater amount of damage in most cases. The selection of factors for an experiment then should not only be directed toward including the most important factors affecting life but should seek to apply them in combination since this allows the evaluation of synergistic effects and more closely simulates actual operating conditions.

The goal of an experiment or test program to generate reliability information is therefore to determine the manner in which a part's life characteristics vary over the envelope of environmental and operating stresses to which it will be subjected during normal application. If all the stresses to which it is to be subjected during normal applications are included in the experiment and are evaluated, the size and expense of the experiment required would be prohibitive in nearly every case. The decision as to which stresses to include must therefore be based on experience, knowledge of failure theory, historical data, failure mode analysis, or predicted values in order to yield the most information for a reasonable expenditure of monies and time.

In addition to being certain to include the most important operating or environmental stresses for inclusion in a reliability data generation program, it is important to evaluate the effects of various levels of the stresses. It is expected in most cases that very little degradation occurs in a so-called laboratory environment. However, the rates of deterioration for a given stress usually vary in some systematic manner over the range of stresses to be encountered in a given application. Therefore, it is desirable to investigate what happens at several points in the environmental and operational envelope.

In determining the most significant stress levels to investigate there are several points to consider. The first is to relate failure mode to stress level. This can be done either by prior knowledge or by running some short time screening tests to locate the general stress level at which failure mode changes can be expected. If these stress levels can be located, they may even be used in influencing the operating or environmental limits to be specified in order to effect a meaningful improvement in product life. Another point to

consider in stress level selection is the concept of endurance limit associated with many nonelectronic parts. This assumes that below certain stress levels life can be considered to be infinite or at least extremely long. Therefore, in order to observe failures in a reasonable time these stress levels must be avoided.

This presents the usual dilemma which can best be solved by step-stress testing as described by Dodson and Howard and by Prot. It consists of testing a specimen or group of specimens for a fixed time at a fixed stress level. The survivors are continued on test at the next increment of higher stress for the same fixed time. This procedure continues until it is possible to select several stress levels suitable for evaluation. The stress levels should not be spaced so closely that no differences can be detected but should be selected to sufficiently cover the spectrum of interest.

The objective of the test program is to generate a mathematical model that demonstrates how life characteristics change as operational or operating stresses or combinations of stresses vary. In the case of nonelectronic parts the dimension of time must also be included in the model since the probability of failure increases as the part sees more service.

In summary, this topic discusses the general ground rules for selecting logical stresses and stress levels when setting up an experiment or test program for evaluating the reliability of nonelectronic parts. The objectives of the guidelines are the generation of more useful data for analysis than is now generally available.

2.2.3 Statistical and Physical Test Design. The goal of the designer of an experiment is the generation of accurate and useful conclusions based on economical test program, efficient data collection methods and the proper selection of statistical methods which will lead to the attainment of the goals.

In generating or gathering reliability data on nonelectronic parts, it is possible to simply put a part or group of parts on test at nominal operating and environmental conditions and collect information on operating times and failure times. From this, it will be possible to estimate the parameters of the assumed failure distribution exhibited by the parts with the methods described in Sections 2.3 and 2.4 of this Notebook.

If a greater degree of diversity is desired because the part of interest frequently may encounter stresses other than nominal in different applications then it is probably wise to attempt to evaluate the effect of a given stress on part life when applied at several different levels. Also, it is probably prudent to investigate the effects of several stresses that are thought to be major factors affecting part life again investigating each of these at several levels. More importantly, it is reasonable to evaluate these stresses when they are applied in combination since this comes the closest to simulating the real life situation.

When it is desired to evaluate stresses applied in combination on a part the most efficient type of statistical experiment to use is some form of factorial design. It is true that it would be possible to evaluate the effect of contact current on the life of a switch by holding all environmental and operating conditions constant while varying the stress of interest, in this case contact current over a desired range of values. This same procedure could then be followed for actuation rate, vibration, temperature and the infinite number of other operating and environmental stresses that could and do affect the life of switches. The obvious result would be a series of tests that would take a rather long time to perform. More importantly, however, is the fact that there would be no measure of how two or more of the stresses might act when both were at levels other than nominal. In other words, if a synergistic effect was brought about by a given set of stresses or stress levels, the aforementioned procedure would not be able to evaluate it. The solution to the problem lies in the use of some form of factorial experiment. There are full factorial experiments in which every combination of stresses and stress levels is tested and perhaps replicated. This type of experimental design yields the maximum amount of information regarding main effects and the effects of interactions of stresses. The price paid for the complete information is paid in the cost of parts placed on test and in the test time required to gather the requisite amount of data needed to perform the analysis.

Fractional factorial experiments can be performed in which some of the test cells in the experiment are omitted in order to reduce test time and expenses. The disadvantages associated with the omission of some stress combinations is that the higher order interactions cannot be evaluated. Therefore, the judgment as to which treatments to omit must be based on experience or opinion. Naturally, those that are not felt to be significant will be omitted. There are several other special types of experimental designs which can be used such as central composites, latin squares and many more. For further information regarding the details of how to set up and analyze this type of experiment the reader is referred to "The Design and Analysis of Industrial Experiments," by O.W. Davies, Hafner Publishing Company, 1954. An example of an application of a full factorial experiment is presented in RADC Technical Report 65-46 "Accelerated Reliability Test Methods for Mechanical and Electromechanical Parts," July 1965. Its Defense Documentation Center number is AD 621074. This report details all the steps necessary in selecting the stresses, stress levels, the development of the statistical test design, the physical test design and all the mathematical analyses required to evaluate the effects of environmental and operating stresses and their interactions on part life. Included also is the methodology for fitting the failure distribution and for estimating the values of the parameters of the Weibull distribution. The details presented in the subject report will serve as a complete example for designing and performing a statistical experiment. The methodology used can be followed in almost a step-by-step manner and can therefore be used in a similar manner as this Notebook. An example of a central composite experimental design is Technical Report ECOM-01433-F "Multi-Pole Relay Evaluation Study," December 1968. The central composite analysis yields a response surface in terms of regression equations involving the main stress effects and certain interactions.

With regard to the physical test design there are a few guidelines that should be followed. The test equipment for generating reliability data for nonelectronic parts should simulate actual operating conditions as accurately as possible. In addition to this the test equipment should be economical to build and use and should yield accurate measurements of the parameters which determine whether or not a part has failed. Finally, the physical test design should include a simple and accurate data collection system. When a large number of parts are tested the record-keeping problems can quickly become quite complex. Therefore, automation of data collection is a commendable goal.

In summary, this section has presented the major types of statistical designs that will yield accurate and useful data and refers the reader to typical sources that will aid in the specification of useful, efficient and economical statistical and physical test designs.

2.3 Fitting Failure Distributions.

2.3.1 Introduction. The two topics immediately following this one deal with specific methods of fitting failure distributions. The placement of this discussion in the overall table of contents is logical because when empirical data are observed the first logical step in its analysis is to attempt to determine the underlying distribution of failure times. While a method for small sample sizes is presented as well as one for large sample sizes it is a fact of life that must be accepted that tests based on small samples are simply not very powerful. Therefore, the methodology is presented here for completeness but very likely a more logical approach is to first make an assumption regarding the failure distribution based on engineering judgment or on historical data or on knowledge of the failure characteristics of similar parts. Once the failure distribution has been assumed the test can be performed for goodness-of-fit for that particular distribution. If the hypothesized distribution is shown not to fit, it is likely that the assumed distribution was not the one from which the samples were selected. If, however, the goodness-of-fit test shows that the data could have come from the hypothesized distribution, then it is likely that other tests for fit would yield like results.

In summary then, it must be realized that the tests presented in the next two items have limitations. The only cure for these limitations is a larger number of observations. If this proves uneconomical or not feasible from the standpoint of test time required to generate the desired number of failures, then the only alternative is to use the results of small sample size analyses with proper discretion.

2.3.2 Small Sample Sizes (Kolmogorov-Smirnov).

1. When to Use

   When failure times from a relatively small sample have been observed and it is desired to determine the underlying distribution of failure times.

2. Conditions for Use

   a. Usually historical data or engineering judgment suggests that part failure times of interest are from a given statistical failure distribution. This test then follows the step of assuming a given failure distribution and is useful to determine if empirical data disproves this hypothesis.

   b. The Kolmogorov-Smirnov test for goodness of fit is distribution free and can therefore be used regardless of the failure distribution that the data is assumed to follow.

   c. The discriminating ability of the statistical test is dependent on sample size so naturally the larger the sample size the more reliable the results. Where large sample sizes are available the χ^2 Test for Goodness-of-Fit should be used. Where sample sizes are small the Kolmogorov-Smirnov test provides some assurance.

d. Strictly speaking, this test method requires prior knowledge of the parameters. If the parameters are estimated from the sample the exact error risks are given in Lawless (1982). However, the values from a Kolmogorov-Smirnov table will provide an adequate approximation in most circumstances.

3. <u>Method</u> / <u>Example</u>

Method	Example
a. Observe and record part failure times.	a. Given the following 20 failure times in hours

92	640
130	700
233	710
260	770
320	830
325	1010
420	1020
430	1280
465	1330
518	1690

Method	Example
b. Assume a distribution of failure times based on historical information or on engineering judgment.	b. Assume failure times are distributed according to the two parameter Weibull distribution.
c. Estimate the parameters of the assumed distribution from the observed data.	c. By the method of least squares (see Section 2.4.2.1.1) the Weibull shape parameter (β)=1.50 and the Weibull scale parameter (α)=28400.
d. Calculate the probability of failure for each observation from the cumulative failure function for the assumed distribution.	d. For the Weibull distribution the cumulative failure function is

$$\hat{F}(x) = 1 - \exp\left(-\frac{x^{\beta}}{\alpha}\right)$$

where x = observed failure time
β=1.5 = Weibull shape parameter
α=28400 = Weibull scale parameter
$\hat{F}(x)$ = probability of failure at or before time x.

3. <u>Method</u>

<u>Example</u>

d. (Continued)

For the 20 observations of this example, the probability of failure at the respective x's is:

x	$\hat{F}(x)$
92	0.03
130	0.05
233	0.12
260	0.14
320	0.18
325	0.19
420	0.26
430	0.27
465	0.30
518	0.24
640	0.43
700	0.48
710	0.49
770	0.53
830	0.57
1010	0.68
1020	0.68
1280	0.80
1330	0.82
1690	0.91

e. Calculate the percentile for each of (i) failure times by the relationship

$F(i) = \frac{i}{n}$ and subtract these respective values from those of step d. above. Record the absolute value of the difference. Also, shift i to i-1 and compute the differences once again.

e. For n=20, $\frac{i}{n}$ gives the following results:

$\hat{F}(x)$	$F(i)$	$F(i-1)$	$\lvert \hat{F}(x) - F(i) \rvert$	$\lvert \hat{F}(x) - F(i-1) \rvert$
0.03	0.05	0	0.02	0.03
0.05	0.10	0.05	0.05	0.00
0.12	0.15	0.10	0.03	0.02
0.14	0.20	0.15	0.06	0.01
0.18	0.25	0.20	0.07	0.02
0.19	0.30	0.25	0.11	0.06
0.26	0.35	0.30	0.09	0.04
0.27	0.40	0.35	0.13	0.08
0.30	0.45	0.40	0.15	0.10
0.34	0.50	0.45	0.16	0.11
0.43	0.55	0.50	0.12	0.07
0.48	0.60	0.55	0.12	0.07
0.49	0.65	0.60	0.16	0.11
0.53	0.70	0.65	0.17	0.12

3. Method

f. Compare the largest difference from step e. with a value at the desired significance level in the Kolmogorov-Smirnov Tables to test for goodness-of-fit. If the tabled value is not exceeded then it is not possible to reject the hypothesis that the failure times are from the assumed distribution.

Example

e. (Continued)

$\hat{F}(x)$	$F(i)$	$F(i-1)$	$\lvert\hat{F}(x) - F(i)\rvert$	$\lvert\hat{F}(x) - F(i-1)\rvert$
0.57	0.75	0.70	0.18	0.13
0.68	0.80	0.75	0.12	0.07
0.68	0.85	0.80	0.17	0.12
0.80	0.90	0.85	0.10	0.05
0.82	0.95	0.90	0.13	0.08
0.91	1.00	0.95	0.09	0.04

f. The largest difference in step e. was .18. From the Kolmogorov-Smirnov Table for a significance of .05 and for a sample of size 20 a difference of greater than .29 must be observed before it can be said that the data could not have come from a Weibull distribution with $\beta=1.5$, $\alpha=28400$.

4. For Further Information

The example presented here illustrates how to test the hypothesis that the failure data came from the Weibull distribution. The Kolmogorov-Smirnov Test can also be used for other failure distributions by properly estimating the parameters in step c. for the appropriate distribution and by using the appropriate cumulative distribution function in step d. Kolmogorov-Smirnov Tables are available on pages 321 and 322 of the Handbook of Tables for Probability and Statistics, Edited by W.H. Beyer, published by the Chemical Rubber Company, Cleveland, Ohio, 1966, and in many texts on statistics.

2.3.3 Large Sample Sizes (χ^2 Test)

1. When to Use

When failure times are available from a relatively large sample and it is desired to determine the underlying distribution of failure times.

2. Conditions for Use

a. In the statistical analysis of failure data it is common practice to assume that failure times follow a given failure distribution family. This assumption can be based on historical data or on engineering judgment. This test for goodness of fit is used to determine if the empirical data disproves the hypothesis of fit to the assumed distribution.

b. The χ^2 test for goodness-of-fit is asymptotically distribution free and can therefore be used regardless of the failure distribution that the data is assumed to follow when samples are large.

c. This test is not directly dependent on sample size but on the number of intervals into which the scale of failure times is divided with the restriction that no interval should be so narrow that there are not at least 5 theoretical failures within the interval. Therefore, the test is only useful if a relatively large number of failures has been observed.

d. A table of χ^2 percentage points is required.

3. Method / Example

a. Observe and record part failure times.

a. The following is the number of cycles to failure for a group of 50 relays on a life test:

1283	6820	16306
1887	7733	17621
1888	8025	17807
2357	8185	20747
3137	8559	21990
3606	8843	23449
3752	9305	28946
3914	9460	29254
4394	9595	30822
4398	10247	38319
4865	11492	41554
5147	12913	42870
5350	12937	62690
5353	13210	63910
5410	14833	68888
5536	14840	73473
6499	14988	

b. Assume a distribution of failure times based on historical information or on engineering judgment.

b. Assume failure times are distributed according to the two parameter Weibull distribution.

c. Estimate the parameters of the assumed distribution from the observed data.

c. By the method of least squares (see Section 2.4.2.1.1) the Weibull shape parameter β=1.21 and the Weibull scale parameter α=127978.

3. Method

d. Divide the spectrum of failure times into intervals of such a width that the theoretical number of failures in each interval will be at least five. The width of intervals need not be equal.

e. Calculate the theoretical number of failures for each interval.

Example

d. Divide the relay cycles to failure into the following intervals:

0	4000
4001	7200
7201	13000
13001	18000
18001	25000
25001	∞

e. The expected number of failures in each interval is obtained as follows:

For the Weibull distribution the cumulative failure function is

$$F(x) = 1 - \exp\left(- \frac{x^{\beta}}{\alpha}\right)$$

where x = observed failure times
β = Weibull shape parameter
α = Weibull scale parameter

Then $F(x_n) - F(x_{n-1})$ = probability a failure time falls within the interval.

Then for each interval the probability of failure in that interval multiplied by the sample size = the theoretical number of failures for each interval.

3. Method

Example

e. (Continued)

(1) Upper Boundary of Interval	(2) F(x)	(3) $F(x_n) - F(x_{n-1})$	(4) Theoretical Failure Frequency (Col. 3x50)
4000	0.16	0.16	8
7200	0.30	0.14	7
13000	0.52	0.22	11
18000	0.66	0.14	7
25000	0.80	0.14	7
∞	1.00	0.20	10

NOTE: The theoretical frequency must not be less than 5 for any interval.

f. Calculate the χ^2 statistic by the formula

$$\chi^2 = \sum_{i=1}^{k} \frac{(f_i - F_i)^2}{F_i}$$

where k = number of intervals
f = observed frequency/interval
F = theoretical frequency/interval

f.

Upper Boundary of Interval	F	f	$\frac{(f_i-F_i)^2}{F_i}$
4000	8	8	0
7200	7	10	1.29
13000	11	12	0.11
18000	7	7	0
25000	7	3	2.29
	10	10	0
	50	50	χ^2=3.69

g. Determine if the χ^2 statistic indicates that the data could have come from the hypothesized distribution using χ^2 tables and $(k-1) - \rho$ degrees of freedom.

where
k = number of intervals
ρ = number of parameters estimated from data

g. The degrees of freedom for this example are calculated as:
d.f. = $(k-1) - \rho$
d.f. = $(6-1) - 2 = 3$
The value from the χ^2 table for 3 degrees of freedom and 0.05 level of significance is 7.815. Since 3.69 does not exceed the tabled value, then the hypothesis that this data came from a Weibull distribution cannot be rejected at the 5% level of significance.

4. For Further Information

The example presented here illustrates how to test the hypothesis that the observed failure data came from the Weibull distribution. The χ^2 test can also be used for other distributions by properly estimating the parameters in step c. for the appropriate distribution and by using the appropriate cumulative distribution function in step c. In step g. the selection of the 5% level of significance was arbitrary and will depend on the researchers willingness to risk a wrong decision in rejecting the hypothesized distribution. There is also a risk of accepting the distribution wrongly which for this test cannot be specified. There are several versions of χ^2 tables but the one used with this example is from "New Tables of the Incomplete Gamma-Function Ratio and of Percentage Points of the Chi-Square and Beta Distributions," by H. Leon Harter, Aerospace Research Laboratories, Office of Aerospace Research, United States Air Force, 1964.

2.4 Estimation Methods

2.4.1 The Exponential Distribution

2.4.1.1 Analytical Point Estimation

1. When to Use

To estimate the parameter θ, mean-time-between-failures, in the exponential distribution function

$$F(x) = 1 - e^{-x/\theta}$$

this computation may be performed. Also, the estimation of reliability is described.

2. Conditions for Use

a. This estimation method may be used when units are selected at random and placed on test, whether or not all units are allowed to fail, and whether or not failed units are replaced.

b. No burn-in or wear-out type failures occur. Use of the exponential distribution assumes a constant failure rate.

c. Total test time and total number of failures must be collected.

3. Method

a. Sum together the test time accumulated on each unit tested to get the total test time. Whether failed units are replaced or not does not affect the calculation, nor does it matter whether all units are allowed to fail. Only compute the total operating time of parts on test.

Example

a. Suppose 10 units are placed on test for 80 hours and the failed units are not replaced. Failures occur at 20, 30, 35, 45, 70 and 75 hours. So, test time accumulates as follows:

Unit 1	20 hours
Unit 2	30 hours
Unit 3	35 hours
Unit 4	45 hours
Unit 5	70 hours
Unit 6	75 hours
Unit 7	80 hours
Unit 8	80 hours
Unit 9	80 hours
Unit 10	80 hours

Total Test Time = 595 hours

3. Method

b. Divide total test time by total number of failures to get an estimate of θ = mean-time-between-failures.

c. The reliability is given by

$$R(x) = 1 - \left(1 - e^{-x/\theta}\right)$$

Example

b. Since the total number of failures is 6, divide

$$\frac{595}{6} = 99.1 \text{ hours.}$$

c. The reliability for 30 hours is estimated to be:

$$R(30) = e^{-30/99.1}$$

$$R(30) = 0.74$$

4. For Further Information

Additional examples on the use of the exponential distribution are presented in "Reliability Theory and Practice," by Igor Bazovsky, Prentice-Hall, 1961.

2.4.1.2 Interval Estimation

2.4.1.2.1 Two-Sided Confidence Limits

1. When to Use

To compute upper and lower confidence limits on the exponential distribution parameter θ (mean-time-between-failures), this method is used.

2. Conditions for Use

a. A confidence level, say $1-\alpha$, must be specified.

b. Total test time and total number of failures must be collected, whether or not failed units are replaced.

c. A table of χ^2 percentage points is required.

3. Method

a. If the test is failure truncated, rather than time truncated, then the lower two-sided confidence limit is

$$\frac{2T}{\chi^2_{2r,1-\alpha/2}}$$

Example

a. Suppose 5 units are placed on life test and fail at 20, 30, 35, 45, and 70 hours. If the 90% confidence limits are desired, then

$$1-\alpha = 0.90$$

$$n = 5$$

3. Method

a. (Continued)

where

T = total test time

$1-\alpha$ = confidence level desired

r = total number of failures

$\chi^2_{2r,1-\alpha/2}$ = $1-\alpha/2$ quantile of the chi-square distribution with $2r$ degrees of freedom.

b. The corresponding upper two-sided confidence limit is

$$\frac{2T}{\chi^2_{2r,\alpha/2}}$$

Example

a. (Continued)

T = 200 hours

$\hat{\theta} = T/r$ = 40 hours

So, the lower two-sided confidence limit is

$$\frac{2 \times 200}{\chi^2_{10,0.95}} = 21.85$$

b. The upper two-sided confidence limit is

$$\frac{2 \times 200}{\chi^2_{10,0.05}} = 101.52$$

4. For Further Information

For a time truncated test, the lower two-sided confidence limit is computed with $2r + 2$ degrees of freedom:

$$\frac{2T}{\chi^2_{2r+2,1-\alpha/2}}$$

The upper two-sided confidence limit is the same as in a failure truncated test, with $2r$ degrees of freedom.

Additional examples demonstrating this method are presented in "Reliability Theory and Practice" by Igor Bazovsky, Prentice-Hall, 1961.

2.4.1.2.2 One-Sided Confidence Limits

1. When to Use

Use this method to compute a lower one-sided confidence limit on the exponential distribution parameter θ (mean-time-between-failures).

2. Conditions for Use

a. A confidence level, say $1-\alpha$, must be specified.

b. Total test time and total number of failures must be collected, whether or not failed units are replaced.

c. Even if no failures have occurred, this method may be used.

d. A table of χ^2 percentage points is required.

3. Method

a. If the test is failure truncated, rather than time truncated,* then the lower one-sided confidence limit is

$$\frac{2T}{\chi^2_{2r,1-\alpha}}$$

where

T = total test time

$1-\alpha$ = confidence level desired

r = total number of failures

$\chi^2_{2r,1-\alpha}$ = $1-\alpha$ quantile of the chi-square distribution with $2r$ degrees of freedom.

*For a time truncated test, the lower one-sided confidence limit is computed with $2r + 2$ degrees of freedom.

$$\frac{2T}{\chi^2_{2r+2,1-\alpha}}$$

NOTE: If no failures have occurred, the lower one-sided confidence limit is $T/(-\ln\alpha)$.

Example

a. Suppose 5 units are placed on life test and fail at 20, 30, 35, 45, and 70 hours. If the 90% lower confidence limit is desired, then

$1-\alpha = 0.90$

$r = 5$

$T = 200$ hours

$\hat{\theta} = T/r = 40$ hours

So, the lower 90% one-sided confidence limit is

$$\frac{2 \times 200}{\chi^2_{10,0.90}} = 25.02$$

4. For Further Information

Additional examples demonstrating this method are presented in "Reliability Theory and Practice" by Igor Bazovsky, Prentice-Hall, 1961.

2.4.2 The Weibull Distribution

2.4.2.1 Analytical Point Estimation

2.4.2.1.1 The Method of Least Squares

1. When to Use

Estimating Weibull shape and scale parameters may be accomplished by fitting a least squares line to transformed Weibull data, provided that the location parameter γ is known or assumed. γ is often assumed to be zero. If not the transformation $X' = X - \gamma$ will reduce to the 2 parameter form. This section of the Notebook on the Weibull distribution contains three methods of estimating the shape and scale parameters. The method of least squares is basically a more accurate version of the graphical method. It takes more calculations to estimate α and β than the graphical method and hence the added cost of these calculations must be balanced against the costs associated with using a less accurate graphical method and being subject to estimation error. While a computer helps reduce calculation time, the least squares method does not require as complex a computer program as the maximum likelihood method although it may not result in as accurate an estimate.

2. Conditions for Use

a. Failure times must be collected.

b. A computer is helpful.

c. A table of median ranks is required. It is provided in Appendix II, Table I.

3. Method

a. For n ordered Weibull failure times $t_1, t_2, \ldots t_n$, find median rank values $F(t_i)$ from Table I in the Appendix.

Example

a. Table I in the Appendix gives the median ranks for these Weibull failure times.

Failure Time	Median Rank
92 Hours	0.0341
130 Hours	0.0831
233 Hours	0.1322
260 Hours	0.1812
320 Hours	0.2302
325 Hours	0.2793
420 Hours	0.3283
430 Hours	0.3774
465 Hours	0.4264
518 Hours	0.4755
640 Hours	0.5245
700 Hours	0.5736

3. Method

Example

a. (Continued)

Failure Time	Median Rank
710 Hours	0.6226
770 Hours	0.6717
830 Hours	0.7207
1010 Hours	0.7698
1020 Hours	0.8188
1280 Hours	0.8678
1330 Hours	0.9169
1690 Hours	0.9659

b. For $i = 1$ to n, let

$$x_i = \ln t_i;$$

$$y_i = \ln\ln \frac{1}{1 - F(t_i)}$$

b. An adapted computer program for fitting least squares lines gives

$\beta = 1.52$

$\alpha = 2.36 \times 10^4$.

c. *Compute

$$\beta = \frac{n \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n \sum_{i=1}^{n} (x_i)^2 - \left(\sum_{i=1}^{n} x_i\right)^2} .$$

d. *Compute

$$\alpha = \exp\left[- \frac{\sum_{i=1}^{n} (x_i)^2 \sum_{i=1}^{n} y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_i y_i}{n \sum_{i=1}^{n} (x_i)^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \right]$$

*NOTE: Steps c. and d. would be lengthy calculations by hand, but a computer program to fit a line $Y = bX + c$ by least squares may be easily adapted to fitting a Weibull line by substituting $\ln t$ for X and $\ln\ln (1/(1-F(t)))$ for Y. Then b will be β and c will be $-\ln \alpha$.

4. For Further Information

Additional examples demonstrating the application of this technique to the estimation of Weibull shape and scale parameters are given in RADC TR65-46 "Accelerated Reliability Testing for Nonelectronic Parts", July 1965, AD 621074.

2.4.2.1.2 Maximum Likelihood Method

1. When to Use

Use this method to estimate the shape (c) and scale (α) parameters of the Weibull cumulative distribution function given by $F(x)=1-\exp(-x^c/\alpha)$. The maximum likelihood method as its name implies is the most accurate based on the observed data. However, the calculations required are the most complex in that an iterative method must be used. If an iterative computer program is utilized the disadvantages of the maximum likelihood method are not so serious. This estimation method must be used for calculating α and c if the interval estimation method of Section 2.4.2.3.1 is to be used for calculating confidence limits.

2. Conditions for Use

a. Failure times must be collected.

b. An iterative computer program is practically essential for economical use of this method.

3. Method

a. Make an initial estimate of the shape parameter (possibly by the graphical method of Section 2.4.2.2). Refer to it as C.

b. Using the first estimate of C, solve the maximum likelihood equation:

$$F = \frac{n}{C} - \frac{n\,\Sigma\left(x_i^C \ln x_i\right)}{\Sigma(x_i)^C} + \Sigma \ln x_i$$

Example

a. The 20 failure times given in Section 2.4.2.1.1 have been plotted on Weibull probability paper in Section 2.4.2.2. The graphical estimate of the shape parameter is 1.5. Therefore, a first iteration of C is 1.5.

b. With C = 1.5, the equation yields F = 1.603. Since F $\neq$ 0, it is necessary to proceed to Step c.

3. Method — Example

b. (Continued)

where

n = sample size

x_i = ith failure time

If when the equation is solved $F = 0$, then C represents the maximum likelihood estimate of the shape parameter. If $F \neq 0$ go to Step c.

c. Take the derivative (with respect to C) of the equation in Step b:

$$F' = -\frac{n}{C^2} - \frac{\left\{\Sigma x_i^C\ \Sigma\left(x_i^C \ln^2 x_i\right) - \left[\Sigma x_i^C \ln x_i\right]^2\right\} \cdot n}{\left(\Sigma x_i^C\right)^2}$$

c. Using $C = 1.5$, $F' = -13.99$.

d. Set $B = C - (F/F')$.

d. $B = 1.5 + 0.115 = 1.615$.

e. Set ϵ = some small number, determined by the accuracy desired in the answer. If accuracy to K places is desired, then set $\epsilon = 10^{-(K+1)}$.

e. Suppose 2 place accuracy is desired, then set $\epsilon = 10^{-3}$.

f. If $|F/F'| \geq \epsilon$, set $C = B$ and repeat Steps b. - f.

f. $|F/F'| = 0.115$.
$0.115 > 10^{-3}$ so set $C = B$ and return to Step b. The iterative process eventually gives $C = \hat{C} = 1.62$.

g. Now it is necessary to apply the unbiasing factor to the maximum likelihood estimate. Appendix Table XI gives factors to be multiplied to the maximum likelihood estimate.

g. From Appendix Table XI the unbiasing factor for a sample size of 20 is 0.931.

Therefore

$$\hat{c} = 0.931(1.62) = 1.51.$$

3. Method

h. To solve for the Weibull scale parameter α

$$\hat{\alpha} = \Sigma x_i^{\hat{c}}/n$$

Example

h. The estimate of the Weibull scale parameter is

$$\hat{\alpha} = 4.47 \times 10^4$$

4. For Further Information

The statistical theory developing the use of this method is presented in "Inferences on the Parameters of the Weibull Distribution," by Thoman, Bain and Antle, Technometrics, Vol. 11, No. 3, August 1969, pp. 445-460.

2.4.2.2 Graphical Point Estimation

1. When to Use

Estimates of the Weibull shape and scale parameters may be obtained graphically by using specially prepared Weibull probability paper. The decision to use this method over those described in the two previous topics should be based wholly on the accuracy desired. This method is the least accurate but can be done quickly and easily.

2. Conditions for Use

a. Failure times must be collected.

b. Median rank tables are required. They are provided in the Appendix, Table I.

c. Weibull probability paper is required. See Figure 2.4.2.2.

3. Method

a. To plot the i^{th} failure time in a set of n ordered failure times, find the median rank plotting position on the left-hand ordinate by consulting the table of median ranks at n, i. To obtain median ranks for n greater than twenty, the following formula may be used:

$$\text{Median rank } (n, i) = \frac{i - 0.3}{n + 0.4},$$

where

i = order number of failure

n = number of failures.

Example

a. As an example of plotting failure times on Weibull probability paper, consider a case in which 20 items are all tested to failure; the 20 failure times, in ascending order, are given below in the left-hand column. In the right-hand column are the median rank plotting positions for each failure time, obtained from the table of median ranks for n = 20 in the Appendix, Table I.

Failure Times (Hours)	Median Ranks
92	0.0341
130	0.0831

3. Method | Example

a. (Continued)

Failure Times (Hours)	Median Ranks
233	0.1322
260	0.1812
320	0.2302
325	0.2793
420	0.3283
430	0.3774
465	0.4264
518	0.4755
640	0.5245
700	0.5736
710	0.6226
770	0.6717
830	0.7207
1010	0.7698
1020	0.8188
1280	0.8678
1330	0.9169
1690	0.9659

Before plotting the data, it is necessary to perform a transformation on the bottom scale to accommodate the large failure times. The axis must be multiplied by 10^{-2} in order for the failure data to fit on the paper. So, the bottom scale is properly labeled HOURS X 10^{-2}.

b. The Weibull line is drawn through the plotted data by using the last point plotted as a reference point for a straight-edge and dividing the rest of the points into two equal groups above and below the line.

b. The Weibull line, labeled ℓ_1 in Figure 2.4.2.2 is drawn as described.

c. To estimate β, parallel to the Weibull line draw a line passing through the small circled point on the paper.

c. The shape parameter β is estimated by drawing the line, labeled ℓ_2, parallel to ℓ_1 and passing through point A.

3. Method / Example

Method	Example
d. Horizontal projection of the point where this line intersects the principal ordinate to the right-hand scale gives $-\beta$. The principal ordinate terminates in 0.0 on the upper scale.	d. The point where ℓ_2 intersects ℓ_3, the principal ordinate, is projected horizontally to the right-hand axis and $-\beta$ read off as -1.5. So, $\beta = 1.5$.
e. Sometimes in order to plot the failure data it is necessary to convert the bottom scale to handle larger numbers. The scales used on this axis are selected for the purpose of convenience in presenting the data on the graph. If the bottom scale has been multiplied by K, then read $-\ln \alpha_K$ at the horizontal projection to the right-hand axis of the intersection of the Weibull line and the principal ordinate.	e. To find α, the intersection of ℓ_1 and ℓ_3 is projected horizontally to the right-hand axis. The value read off the axis, -2.9, is $-\ln \alpha_K$, and must be converted.
f. Find the value of α_K by using a calculator. The computed α_K is a coded value which is dependent on the time scale used.	f. The value of α_K is found to be 18.2.
g. To convert α_K to an uncoded state that is independent of the time scale used on the probability paper, divide α_K by K^β, where β is the previously obtained shape parameter.	g. α_K is converted to an uncoded state by dividing by K^β. So, divide 18.2 by $10^{-2\beta}$ giving $$\alpha = \frac{18.2}{10^{-2\beta}} = 18.2 \times 10^{2 \times 1.5}$$ $$= 1.82 \times 10^4$$

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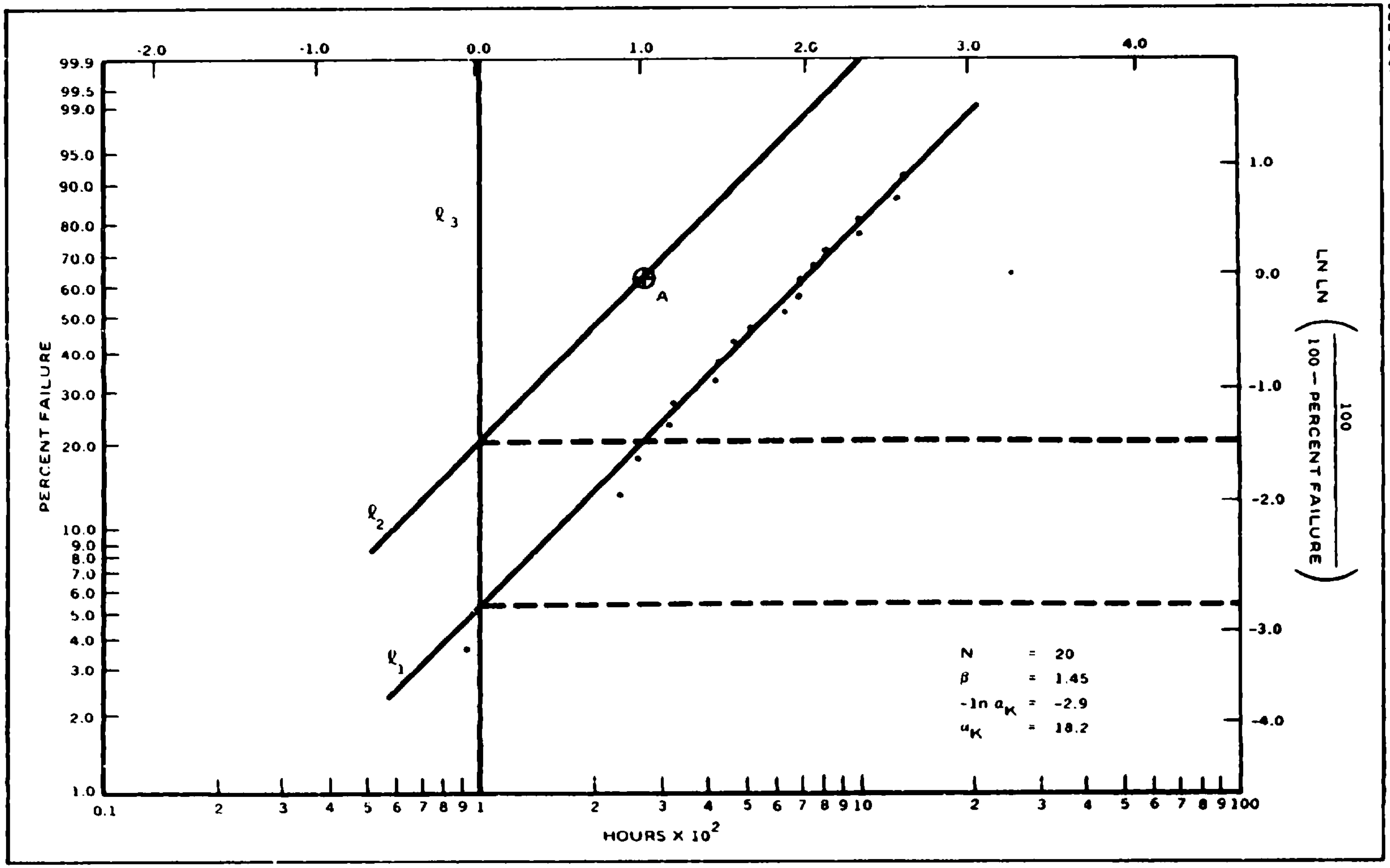

Figure 2.4.2.2. Graphical Point Estimation for the Weibull Distribution

4. <u>For Further Information</u>

If desired, the median ranks may be replaced by the unbiased estimate $i/(n+1)$, where

i = order number of failure

n = number of failures.

2.4.2.3 Interval Estimation

2.4.2.3.1 Weibull Parameters

1. <u>When to Use</u>

Use this method to obtain confidence intervals on the shape (c) and scale (α) parameters of the two parameter Weibull cumulative distribution function given by $F(x) = 1 - \exp(-(x^c)/\alpha)$.

2. <u>Conditions for Use</u>

a. Point estimates of c and α must be made using the method of Section 2.4.2.1.2.

b. The tables required in the calculation are provided in Appendix II, Tables V and VI.

3. <u>Method</u>

a. To compute $100(1-\gamma)$ percent confidence limits on c, locate in Table V the column labeled with the value of $\gamma/2$. Read off the table value at N = sample size and call it L_1. Locate the column labeled with the value of $1 - \gamma/2$. Read off the table value at N = sample size and call it L_2. Then, the confidence interval on c is of the form $(\hat{c}/L_2, \hat{c}/L_1)$, where c was obtained by the method of Section 2.4.2.1.2.

b. To compute $100(1-\gamma)$ percent confidence limits on α, locate in Table VI the column labeled with the value of $\gamma/2$. Read off the table value at N = sample size and call it t_1. Locate the column labeled with the value

<u>Example</u>

a. Suppose it is desired to compute 90% confidence limits on the Weibull parameters for the example given in Section 2.4.2.1.2. Then N = 20, γ = 0.10, c = 1.51 and $\hat{\alpha} = 4.47 \times 10^4$. From Table V, at N = 20 in the 0.05 column the value of L_1 is read as 0.791 and at N = 20 in the 0.95 column the value at L_2 as 1.449. So the interval on $\hat{c}$ is (1.51/1.449, 1.51/0.791) = (1.04, 1.91).

b. The 90% confidence interval on α requires consulting Table VI:

$t_1 = -0.428$

$t_2 = 0.421$

3. Method

b. (Continued)

at $1 - \gamma/2$. Read off the table value at N = sample size and call it t_2. Then, the confidence interval on α is of the form

$$\left(\hat{\alpha} \exp(-t_2),\ \hat{\alpha} \exp(-t_1)\right),$$

where $\hat{\alpha}$ was obtained by the method of Section 2.4.2.1.2.

Example

b. (Continued)

The interval on α is given by

$$\left[4.47 \times 10^4 \exp(-0.421),\right.$$

$$\left.4.47 \times 10^4 \exp(0.428)\right]$$

$$= (2.93 \times 10^4,\ 6.87 \times 10^4)$$

4. For Further Information

This method is from "Inferences on the Parameters of the Weibull Distribution," Thoman, Bain and Antle, Technometrics, Vol. II, No. 3, August 1969, pp. 445-460.

2.4.2.3.2 Reliability

2.4.2.3.2.1 Uncensored Samples

1. When to Use

Use this method to estimate 90% confidence limits on reliability for the Weibull distribution.

2. Conditions for Use

a. A plot of the failure times must be prepared on Weibull probability paper. See Section 2.4.2.2 for the methodology.

b. A table of 5% ranks and one of 95% ranks are required. These are provided in Appendix II, Tables II and III.

3. Method

a. Draw the Weibull line for the observed data, as described in Section 2.4.2.2.

b. Locate the median ranks on the left-hand axis, project them horizontally and mark their intersection with the Weibull line.

Example

a. Refer to the example of 20 failure times used in Section 2.4.2.2. The Weibull line on Weibull probability paper is presented here again, Figure 2.4.2.3.2.1.

b. The following median ranks, for n = 20, have been marked on the Weibull line:

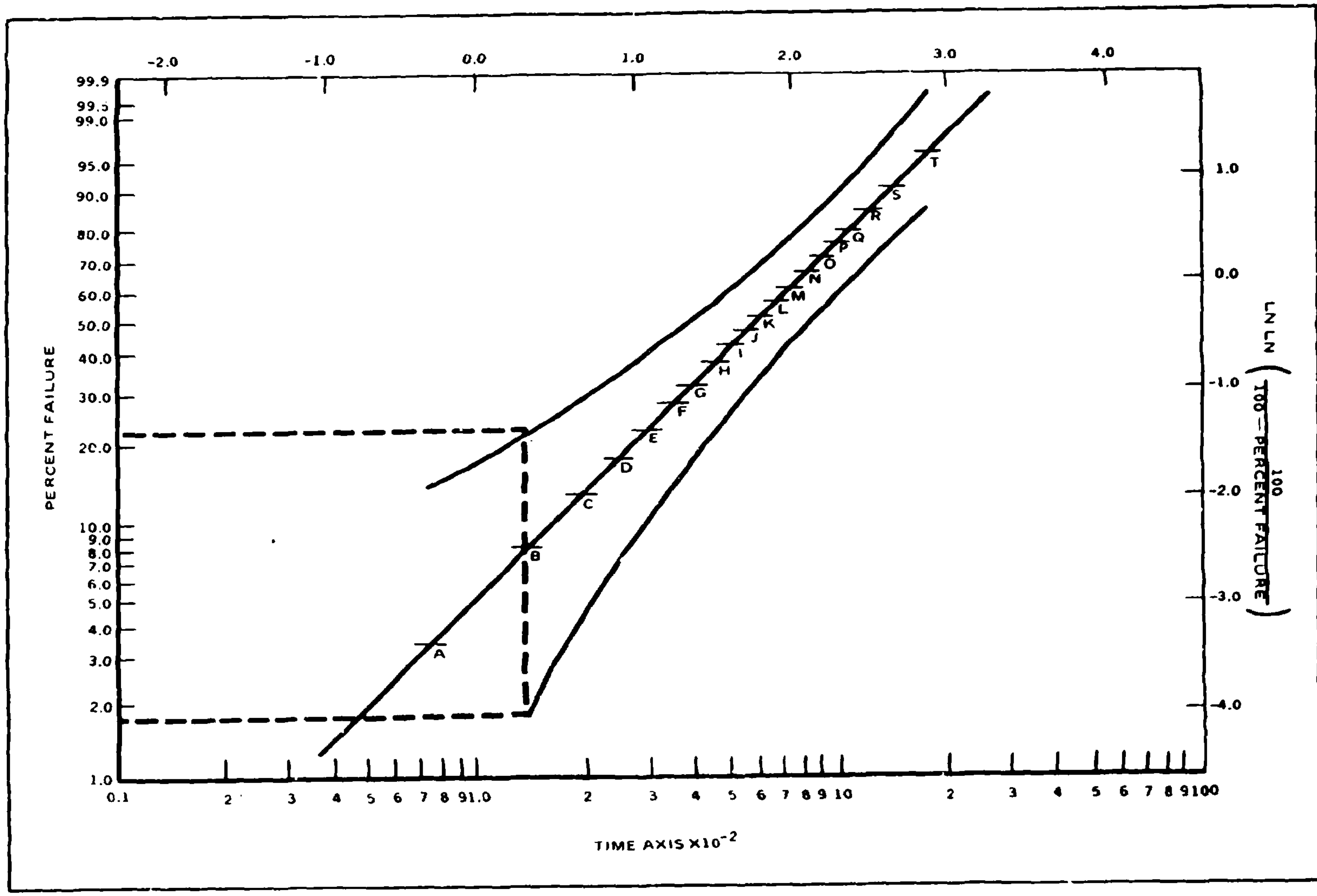

Figure 2.4.2.3.2.1. Graphical Method for Interval Estimation of Reliability for the Weibull Distribution

3. Method

Example

b. (Continued)

Median Rank	Graph Notation
0.0341	A
0.0831	B
0.1322	C
0.1812	D
0.2302	E
0.2793	F
0.3283	G
0.3774	H
0.4264	I
0.4755	J
0.5245	K
0.5736	L
0.6226	M
0.6717	N
0.7207	O
0.7698	P
0.8188	Q
0.8678	R
0.9169	S
0.9659	T

c. For the j^{th} plotting position of sample size = n, find the 5% and 95% ranks from Tables II and III. Locate them on the left-hand axis of the Weibull paper, then project them horizontally. Their intersection with a vertical line drawn through the previously marked point of intersection of the j^{th} median rank and the Weibull line gives the lower and upper limits on reliability for that point on the time (lower) axis.

c. The tables show a 5% rank value of 0.0183 and a 95% rank value of 0.2182 for n = 20, j = 2. So, these plots have been plotted on the vertical line through point B.

d. Continue plotting each pair of upper and lower limits for all n failures. Then connect the points above the Weibull line with a smooth curve. Likewise connect the points below the Weibull line, thus forming a band around the Weibull line, narrowing at the center and widening at both ends.

d. Curves are drawn through the plotted points.

3. <u>Method</u>

e. To find limits on reliability at a particular time t, locate t on the lower axis and read off upper and lower limits on reliability from the two curves by referring to the left-hand axis.

<u>Example</u>

e. For example, the confidence limits on reliability at 400 hours are 0.19 and 0.49.

4. **For Further Information**

Tables II and III for 5% and 95% ranks are from Electromechanical Component Reliability, May 1963, Chernowitz, et.al., RADC-TDR-63-295, American Power Jet, Ridgefield, N.J.

If confidence intervals other than the 90% for $n \leq 20$ given here are desired, any percentile ranks may be obtained in the following manner for sample sizes up to 50. Tables of the Incomplete Beta Function are required. The notation used here is found in Tables of the Incomplete Beta Function, K. Pearson, Cambridge University Press, 1956.

<u>Method</u>

a. For the j^{th} failure of n failures, compute

$$k = n - j + 1$$

For $j \geq k$ let $p = j$, $q = k$.

For $j < k$ let $p = k$, $q = j$.

b. To compute $100\,(1-\alpha)$ percent confidence limits, locate values of $I_x(p,q)$ in Table I of the referenced tables, such that $\alpha/2$ and $1-\alpha/2$ are approximated as closely as possible. For $j \geq k$, the γ percentile rank, where $\gamma = \alpha/2,\ 1-\alpha/2$, is given by the x in the left-hand column on the same row as the value of $I_x(p,q) = \gamma$.

<u>Example</u>

a. Suppose n = 10 and it is required to find the 80% confidence limits on reliability. Then the following table may be constructed:

j	k	q	p
1	10	1	10
2	9	2	9
3	8	3	8
4	7	4	7
5	6	5	6
6	5	5	6
7	4	4	7
8	3	3	8
9	2	2	9
10	1	1	10

b. To compute 80% confidence limits, the 0.10 and 0.90 percentile ranks are needed. So, in Table I find the $\gamma = 0.10$ and $\gamma = 0.90$ percentile ranks for j=1 on pp. 22, 23, for p = 10 and q = 1. The value of x opposite 0.0946828 in the table, the closest value to 0.1 given, is 0.79, and the value of x opposite 0.9043821, closest to 0.9, is 0.99. So, the

Method

b. (Continued)

For $j < k$, the γ percentile rank is given by $1-x$, where x again is in the left-hand column on the same row as the value of $I_x(p,q) = \gamma$.

Example

b. (Continued)

desired percentile ranks for $n = 10$, $j = 1$ are 90%: $1 - 0.79 = 0.21$; 10%: $1 - 0.99 = 0.01$.

The complete set of percentile ranks follows, as computed from Table I.

j	90%	10%
1	0.21	0.01
2	0.40	0.06
3	0.51	0.09
4	0.55	0.19
5	0.65	0.26
6	0.74	0.35
7	0.81	0.45
8	0.91	0.49
9	0.94	0.6
10	0.99	0.79

2.4.2.3.2 Reliability

2.4.2.3.2.2 Censored Samples

1. **When to Use**

This section describes a procedure for calculating a lower confidence limit on reliability for parts which are known to have Weibull failure distributions. The method is applicable to both censored and uncensored test data.

2. **Conditions for Use**

a. Failure times must be collected.

b. Certain tables are required in the calculation. They are provided in Appendix II, Tables VII and VIII.

3. **Method**

a. For a test of n items, r of which are allowed to fail before termination of the test, order the r failure times and for $i = 1$ to r, set X_i = ith failure time.

Example

a. Suppose 20 parts are put on test and the test terminates after the 10th failure. Then $n = 20$, $r = 10$, and suppose the following failure times are observed:

3. Method

Example

a. (Continued)

$X_1 = 92$ hours
$X_2 = 130$ hours
$X_3 = 233$ hours
$X_4 = 260$ hours
$X_5 = 320$ hours
$X_6 = 325$ hours
$X_7 = 420$ hours
$X_8 = 430$ hours
$X_9 = 465$ hours
$X_{10} = 518$ hours

b. To find the lower confidence limit at time t_o, compute for $i = 1$ to r

$$Y_i = \ln X_i - \ln t_o$$

b. Suppose it is desired to find the 95% lower confidence limit on R(50), reliability at 50 hours. Then $\ln (50) = 3.91202$ and

$Y_1 = 0.60977$
$Y_2 = 0.95551$
$Y_3 = 1.53902$
$Y_4 = 1.64866$
$Y_5 = 1.85630$
$Y_6 = 1.87181$
$Y_7 = 2.12823$
$Y_8 = 2.15177$
$Y_9 = 2.23002$
$Y_{10} = 2.33796$

c. Let $p = r/n$ and find values in Table VII for a_i and b_i, for $i = 1$ to r.

c. Since $p = 10/20$, Table VII gives the following values for a_i's and b_i's.

$a_1 = -0.04527$ $b_1 = -0.09198$
$a_2 = -0.04032$ $b_2 = -0.09230$
$a_3 = -0.03371$ $b_3 = -0.09010$
$a_4 = -0.02574$ $b_4 = -0.08597$
$a_5 = -0.01650$ $b_5 = -0.08013$

3. Method

Example

c. (Continued)

$a_6 = -0.00596 \qquad b_6 = -0.07264$

$a_7 = 0.00595 \qquad b_7 = -0.06345$

$a_8 = 0.01935 \qquad b_8 = -0.05246$

$a_9 = 0.03444 \qquad b_9 = -0.03948$

$a_{10} = 1.10777 \qquad b_{10} = 0.66851$

d. Compute

$$Z_a = \sum_{i=1}^{r} a_i Y_i$$

$$Z_b = \sum_{i=1}^{r} b_i Y_i$$

d.
$$\begin{aligned} Z_a = & (-0.04527)(0.60977) \\ & + (-0.04032)(0.95551) \\ & + (-0.03371)(1.53902) \\ & + (-0.02574)(1.64866) \\ & + (-0.01650)(1.85630) \\ & + (-0.00596)(1.87181) \\ & + (0.00595)(2.12823) \\ & + (0.01935)(2.15177) \\ & + (0.03444)(2.23002) \\ & + (1.10777)(2.33796) \\ = & \ 2.5188 \end{aligned}$$

$$\begin{aligned} Z_b = & (-0.09198)(0.60977) \\ & + (-0.09230)(0.95551) \\ & + (-0.09010)(1.53902) \\ & + (-0.08597)(1.64866) \\ & + (-0.08013)(1.85630) \\ & + (-0.07264)(1.87181) \\ & + (-0.06345)(2.12823) \\ & + (-0.05246)(2.15177) \\ & + (-0.03948)(2.23002) \\ & + (0.66851)(2.33796) \\ = & \ 0.5176 \end{aligned}$$

e. Compute

$$Z_a/Z_b$$

e. $Z_a/Z_b = 4.87$

f. To find the lower confidence limit on reliability with confidence coefficient γ, use Table VIII and find the value of $L^*(Z_a/Z_b)$ in the column with the desired γ heading. It is the exact lower confidence bound for $R(t_o)$, reliability at time t_o.

f. Referring to Table VIII,

$$L^*(Z_a/Z_b) = L^*(4.87) = 0.939$$

So, the lower 95% confidence limit on reliability at 50 hours is 0.939.

3. Method

g. A point estimate of $R(t_0)$, reliability at time t_0, is given by

$$R(t_0) = \exp(-\exp(-Z_a/Z_b)).$$

Example

g. Reliability at 50 hours is given by

$$\exp(-\exp(-4.87)) = 0.991.$$

4. For Further Information

a. The method given in this section is from "An Exact Asymptotically Efficient Confidence Bound for Reliability in the Case of the Weibull Distribution," Johns and Lieberman, Technometrics, Vol. 8, No. 1, February 1966, pp. 135-175. That paper also includes an estimation method for obtaining a lower confidence limit on reliability for large sample sizes.

b. A graphical technique for obtaining two-sided confidence limits on reliability is given in Section 2.4.2.3.2.1.

2.4.3 The Normal Distribution

2.4.3.1 Analytical Point Estimation

1. When to Use

Use this method to obtain estimates of μ and σ, the mean and standard deviation of the Normal distribution. The choice of this method over the graphical method described in the next topic is a matter of the accuracy desired, with this one yielding the most accurate estimate.

2. Conditions for Use

Failure times must be collected and data must be uncensored.

3. Method

a. The sample mean, $\bar{x}$, is an estimate of μ and is given by

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n},$$

where

x_i = ith failure time

n = sample size.

Example

a. Suppose 20 units are tested to failure and the following failure times observed:

175 hours
695 hours
872 hours
1250 hours
1291 hours
1402 hours
1404 hours
1713 hours
1741 hours
1893 hours
2025 hours
2115 hours

3. Method

b. The sample standard deviation s is an estimate of σ and is given by

$$s = \left(\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{(n - 1)} \right)^{1/2},$$

where

x_i = ith failure time

n = sample size

$\bar{x}$ = sample mean.

An alternate form, useful in computer programming of this method is

$$s = \left(\frac{\sum_{i=1}^{n} x_i^2}{(n - 1)} - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n(n - 1)} \right)^{1/2}$$

Example

a. (Continued)

2172 hours
2418 hours
2583 hours
2725 hours
2844 hours
2980 hours
3268 hours
3538 hours

Then n = 20, so

$$\bar{x} = \sum_{i=1}^{20} \frac{x_i}{20} = 1955.2 \text{ hours}$$

b. The sample standard deviation calculation gives

$$s = 886.6 \text{ hours}$$

4. For Further Information

Additional information regarding these estimation methods can be obtained from any text on elementary statistics.

2.4.3.2 Graphical Point Estimation

1. When to Use

This method estimates μ and σ, the mean and standard deviation when failure times are normally distributed. This method yields a less accurate estimate than the method of the previous topic but requires very minimal calculations.

2. Conditions for Use

a. Failure times must be collected, but may be censored.

b. Normal probability paper is required.

3. Method

a. On normal probability paper, plot the ith failure time in a sample of n ordered failure times on the lower axis vs i/(n+1) on right-hand axis.

b. Draw the Normal line of best fit through the plotted points by using the last point plotted as a reference point for a straight-edge and dividing the rest of the points into two

Example

a. The sample data used on the example for Section 2.4.3.1 is repeated here, with the necessary plotting positions.

Failure Time	Plotting Position i/(n+1)
175 hours	0.05
695 hours	0.10
872 hours	0.14
1250 hours	0.19
1291 hours	0.24
1402 hours	0.29
1404 hours	0.33
1713 hours	0.38
1741 hours	0.43
1893 hours	0.48
2025 hours	0.52
2115 hours	0.57
2172 hours	0.62
2418 hours	0.67
2583 hours	0.71
2725 hours	0.76
2844 hours	0.81
2980 hours	0.86
3268 hours	0.90
3538 hours	0.95

b. Figure 2.4.3.2 is the plot of this data on normal paper. The normal line has been labeled ℓ_1.

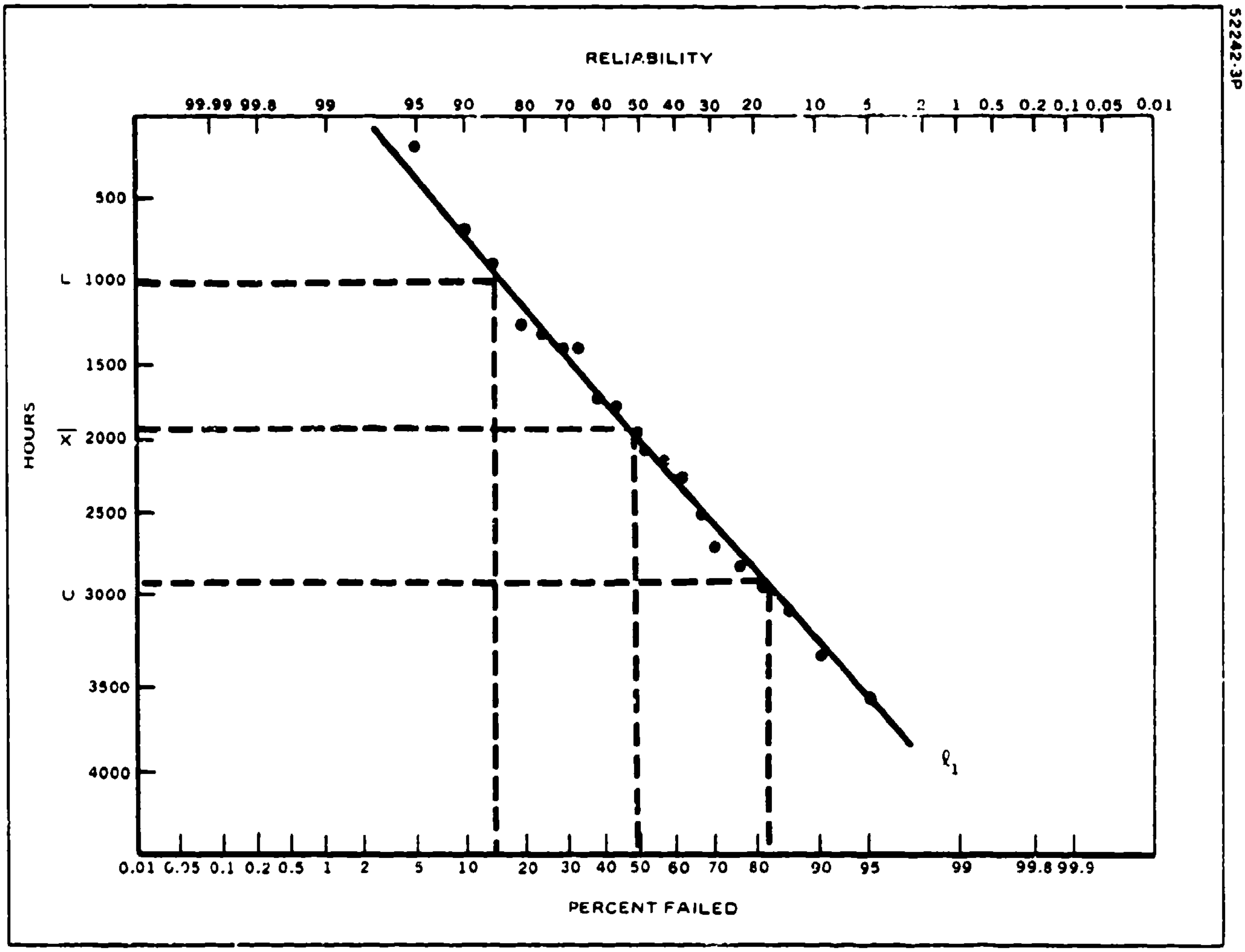

Figure 2.4.3.2. Graphical Point Estimation for the Normal Distribution

3. Method	Example
b. (Continued) equal groups above and below the line.	
c. The mean, μ, is estimated by projecting the 50% probability of failure point on the right-hand axis to the normal line and then projecting that intersection point down to the lower axis. The estimate of μ, $\bar{x}$, is read off there.	c. The value of $\bar{x}$ is read off as 1950 hours.
d. The estimate of σ, s, is obtained by projecting the intersection of the 84% probability of failure point on the right-hand axis with the normal line to the lower axis. Call that point on the lower axis U.	d. U = 2900 hours.
e. Repeat Step d. with the 16% point. Call the point L.	e. L = 1000 hours.
f. The estimate of σ is $s = \frac{U - L}{2}$	f. The sample standard deviation, s, is $\frac{U - L}{2} = \frac{2900 - 1000}{2} = 950$ hours

4. For Further Information

Additional examples of the use of this estimation method are presented in most texts on elementary statistics.

2.4.3.3 Interval Estimation

2.4.3.3.1 Small Sample Sizes (σ unknown)

1. When to Use

Use this method to obtain confidence limits on the mean of the Normal distribution for sample sizes < 30.

2. Conditions for Use

a. Estimates of the mean and standard deviation must be available. See Section 2.4.3.1 for method of computing.

b. A table of percentiles of Student's t distribution is required.

3. Method

a. To find two-sided* 100(γ) per cent confidence limits on μ, consult a table of the percentiles of the t distribution, for the value of $t_{(1+\gamma)/2,n-1}$ where t is Student's t with n-1 degrees of freedom.

b. The two-sided confidence limits are given by

$$\bar{x} \pm t_{(1+\gamma)/2,n-1}\ s/\sqrt{n}\ ,$$

where $\bar{x}$ = sample mean

s = sample standard deviation

n = sample size

*NOTE: One-sided 100(γ) per cent confidence limits are given by

upper only $\rightarrow \bar{x} + t_{\gamma,n-1}\ s/\sqrt{n}$

lower only $\rightarrow \bar{x} - t_{\gamma,n-1}\ s/\sqrt{n}$

Example

a. Consider the 20 failure times used as an example in Section 2.4.3.1,

where $\bar{x}$ = 1955.2 hours

s = 886.6 hours

To obtain two-sided 95% confidence limits on μ, the value of t is needed. From a table of percentiles of the t distribution it is seen to be 2.093.

b. The confidence limits are then

$$1955.2 \pm 2.093 \times \frac{886.6}{4.47}$$

$$= (1540.1,\ 2370.3)$$

If it were desired to calculate a lower one-sided 80% confidence limit on μ, it would be given by

$$1955.2 - 0.861 \times \frac{886.6}{4.47}$$

$$= 1784.$$

4. For Further Information

Additional examples demonstrating this method are presented in "Reliability Handbook" edited by W. Grand Ireson, McGraw-Hill, 1966.

2.4.3.3.2 Large Sample Sizes (σ unknown)

1. When to Use

Use this method to obtain confidence limits on the mean of the Normal distribution for sample sizes $\geq$ 30. If the standards deviation is unknown, Student's t distribution holds. However, for sample sizes of 30 or more the Normal distribution approximates the t distribution.

2. Conditions for Use

a. Estimates of the mean and standard deviation must be available. See Section 2.4.3.1 for method of computing.

b. A table of standardized normal variates is required.

3. Method

a. To find two-sided $100(\gamma)$ confidence limits on μ, consult a table of standardized normal deviates for the value of $Z_{(1+\gamma)/2}$, where Z is the standardized normal variate and $(1+\gamma)/2$ is the area under the curve to be found in the table.

b. The approximate two-sided confidence limits are given by

$$\bar{x} \pm Z_{(1+\gamma)/2}\ s/\sqrt{n}$$

where $\bar{x}$ = sample mean

s = sample standard deviation

n = sample size

c. One-sided $100(\gamma)$ percent confidence limits are given by

upper only $\bar{x} + Z_{\gamma}\ s/\sqrt{n}$

lower only $\bar{x} - Z_{\gamma}\ s/\sqrt{n}$

Example

a. Suppose, after testing 50 items to failure, the sample mean and standard deviation are found to be

$\bar{x}$ = 3780 hours

s = 1440 hours

by the methods of Section 3.4.3.1. Suppose, it is desired to find two-sided 90% confidence on μ. Then, from a table of standard normal deviates,

$$Z_{(1+0.90)/2} = 1.645.$$

b. The confidence limits are then

$$3780 \pm 1.645 \times \frac{1440}{7.07} = (3445,4115)$$

c. If it were desired to calculate an upper one-sided 99% confidence limit on μ, it would be given by

$$3780 + 2.33 \times \frac{1440}{7.07} = 4255.$$

4. For Further Information

Additional examples describing the use of this method are given in "Reliability Handbook" edited by W. Grant Ireson, McGraw-Hill, 1966.

2.4.4 The Log-Normal Distribution. To treat Log-Normal failure data, one procedure is to first take the natural logarithm of each failure time. Then use the methods of Section 2.4.3, the Normal distribution, on the logarithms. The advantage of this procedure is that tables of the standardized Normal deviates may be used in working with the logarithms of the failure times, since they are Normally distributed.

An alternate procedure for treating Log-Normal data is to use Table IV in Appendix II. Its advantage is that logarithms of the failure times do not have to be computed.

Use of Table IV

Method

a. For n Log-Normally distributed failure times x_i, compute

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}$$

and

$$s = \left(\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1} \right)^{1/2}$$

b. To find the γ percentile value, located in Table IV the column headed "γ Percentile." Read off the value in this column opposite the value of $s/\bar{x}$ in the left-hand column. Call it p.

c. The γ percentile is estimated by $p\bar{x}$.

Example

a. Consider the following set of 6 Log-Normally distributed failure times:

5.53 hours
5.70 hours
6.62 hours
7.61 hours
8.33 hours
8.76 hours

Then

$\bar{x} = 7.09$ hours

$s = 1.36$ hours

b. To find the 5th percentile, that column in the table is consulted and the value located opposite $s/\bar{x} = 1.36/7.09 \quad 0.19$ is read off as $p = 0.72$.

c. The 5th percentile then is $0.72 \times 7.09 = 5.1$. This can be interpreted as an estimate of the reliability ($R_{0.95}$).

Additional Applications

a. If it is desired to find some percentile other than those presented in the table the following formula will be useful:

Let p_i = the desired percentile

μ_x = the mean of the observations which are assumed to be Log-Normally distributed

σ_x^2 = the variance of the observations which are assumed to be Log-Normally distributed

Z_i = the standard Normal deviate associated with p_i

Then

$$p_i = \frac{\mu_x^2}{\left[\mu_x^2 + \sigma_x^2\right]^{1/2}} \exp\left[Z_i\left(\log\left[\frac{\sigma_x^2 + \mu_x^2}{\mu_x^2}\right]\right)^{1/2}\right]$$

b. If the observations are in logarithmic form and a given percentile is desired, the following formula is used:

Let p_i = desired percentile

μ_y = the mean of the $\log_e x_i$'s

σ_y = the standard deviation of the $\log_e x_i$'s

Z_i = the standard Normal deviate associated with p_i

Then

$$p_i = \exp(\mu_y + Z_i\sigma_y)$$

For Further Information

The mathematical theory of this distribution is presented in "The Log-Normal Distribution" by Aitchison and Brown, Cambridge University Press, 1957. The analysis methods and tables accompanying this method were developed and prepared by J.G. Frost, Hughes Aircraft Company, Fullerton, California.

2.4.5 The Extreme Value Distribution

2.4.5.1 Analytical Point Estimation

1. When to Use

When the distribution of failure times follows the extreme value distribution, this method is applicable. The parameter estimates are calculated by the method of moments. A graphical method for parameter estimation is presented in the next topic. The decision whether to use the analytical or graphical method rests in the accuracy desired when compared to the calculations to be performed in the method described here.

2. Conditions for Use

Failure times must be known or assumed to follow the extreme value distribution. Random failure times must be observed.

3. Method / Example

Method

a. Observe the failure times from a randomly selected sample.

b. Calculate estimates of the mean and standard deviation from the sample observations.

c. Estimate the parameters β and m from the following formula:

$$\hat{\beta} = \frac{\sigma_N}{S}$$

$$\hat{m} = \bar{x} - \frac{\bar{Y}_N}{\hat{\beta}}$$

Example

a. Given the following 30 failure times from a process assuming a largest extreme value (L.E.V.) distribution:

Failure Time (Hours)	
220	453
230	455
262	470
288	476
289	517
297	540
312	550
315	552
360	586
369	588
394	633
399	637
412	657
431	690
438	728

b. Using the methods of Section 2.4.3.1, calculate estimates of the mean

$$\bar{x} = 451.6$$

and the standard deviation

$$s = 139.0$$

c. For n=30, Gumbel gives the constants

$$\sigma_N = 1.11238$$

$$\bar{Y}_N = .53662$$

3. Method

c. (Continued)

where σ_N and $\bar{Y}_N$ are two constants which are functions of sample size only. A table of these constants is available in Gumbel, "Statistics of Extremes," Columbia University Press, 1960.

d. Estimate the reliability for any time t from the formula

$$R(t) = 1-e^{-e^{-\hat{\beta}(t-\hat{m})}}$$

Example

c. (Continued)

Then

$$\hat{\beta} = \frac{1.11238}{139.0} = .008$$

$$\hat{m} = 451.6 - \frac{.53662}{.008} = 384.5$$

d. The estimated reliability for a mission of 500 hours is

$$R(500) = 1-e^{-e^{-.008(500-384.5}}$$

$$R(500) = .335$$

4. For Further Information

The example presented in this section is for the Largest Extreme Value (L.E.V.) Distribution. The methods for the Smallest Extreme Value (S.E.V.) Distribution are essentially equivalent.

2.4.5.2 Graphical Point Estimation

1. When to Use

When the distribution of failure times is known or assumed to follow the extreme value distribution, this method is applicable. This method yields somewhat less accurate estimates than the analytical method of Section 2.4.5.1 but does not require the performance of calculations.

2. Conditions for Use

Either random or ordered censored observations may be used to estimate the parameters.

3. Method

a. Collect failure times from a random process and couple them with median ranks $\widehat{F}(x)$ and calculate

$$\ln \ln \frac{1}{F(x)}$$

Example

a. Given 30 random failure times from a process assuming an L.E.V. distribution. Obtain median ranks for n=30 using the method of Section 2.4.2.2 and couple these with the failure times as follows:

3. Method

Example

a. (Continued)

Median Ranks $\hat{F}(x)$	$\ln \ln \frac{1}{\hat{F}(x)}$	Failure Times (Hours)
.023	1.33	220
.056	1.06	230
.089	.88	262
.122	.74	288
.155	.62	289
.188	.52	297
.220	.41	312
.253	.32	315
.286	.22	360
.319	.13	369
.352	.04	394
.385	-.05	399
.418	-.14	412
.451	-.23	431
.484	-.32	438
.516	-.41	453
.549	-.51	455
.582	-.61	470
.615	-.72	476
.648	-.84	517
.681	-.96	540
.714	-1.09	550
.747	-1.23	552
.780	-1.39	586
.813	-1.57	588
.845	-1.78	633
.878	-2.04	637
.911	-2.38	657
.944	-2.86	690
.977	-3.76	728

b. Plot the failure times on the x axis and $\ln \ln \frac{1}{\hat{F}(x)}$ on the y axis and draw a line of best fit through the points.

b. See Figure 2.4.5 for the graph of this data.

c. Estimate parameters β and m from the graph.

c. From the graph the slope is -.0076 and the intercept is 2.85. Then

$$\hat{\beta} = - \text{the slope} = .0076$$

$$\hat{m}\,\hat{\beta} = \text{the intercept}$$

3. Method

Example

d. (Continued)

Therefore

$$\hat{m} = \frac{2.85}{.0076} = 380$$

NOTE: These results agree closely with the results of the analytical method Section 2.4.5.1.

4. For Further Information

The example presented in this section is for the Largest Extreme Value (L.E.V.) Distribution. The method for the Smallest Extreme Value (S.E.V.) Distribu[illegible] is essentially the same. Commercial graph paper is available for plo[illegible] the extreme value distribution.

2.4.5.3 Interval Estimation

1. When to Use

When the distribution of failure times follows the extreme value distribution, this method yields an approximate confidence interval or lower confidence bound for reliability.

2. Conditions for Use

This method is applicable if it is assumed that the sample size, n, is large and that the graphical estimates of parameters, β and m (see Section 2.4.5.2) are maximum likelihood estimates. The actual maximum likelihood estimate values can be obtained only by iteration.

3. Method

Examples

a. Obtain estimates for the parameters β and m using graphical methods of Section 2.4.5.2.

a. From the example in Section 2.4.5.2

$$\hat{\beta} = .0076$$

$$\hat{m} = 380$$

b. Specify the mission time and confidence desired.

b. For a mission time of 300 hours, find a lower 95% confidence bound on reliability.

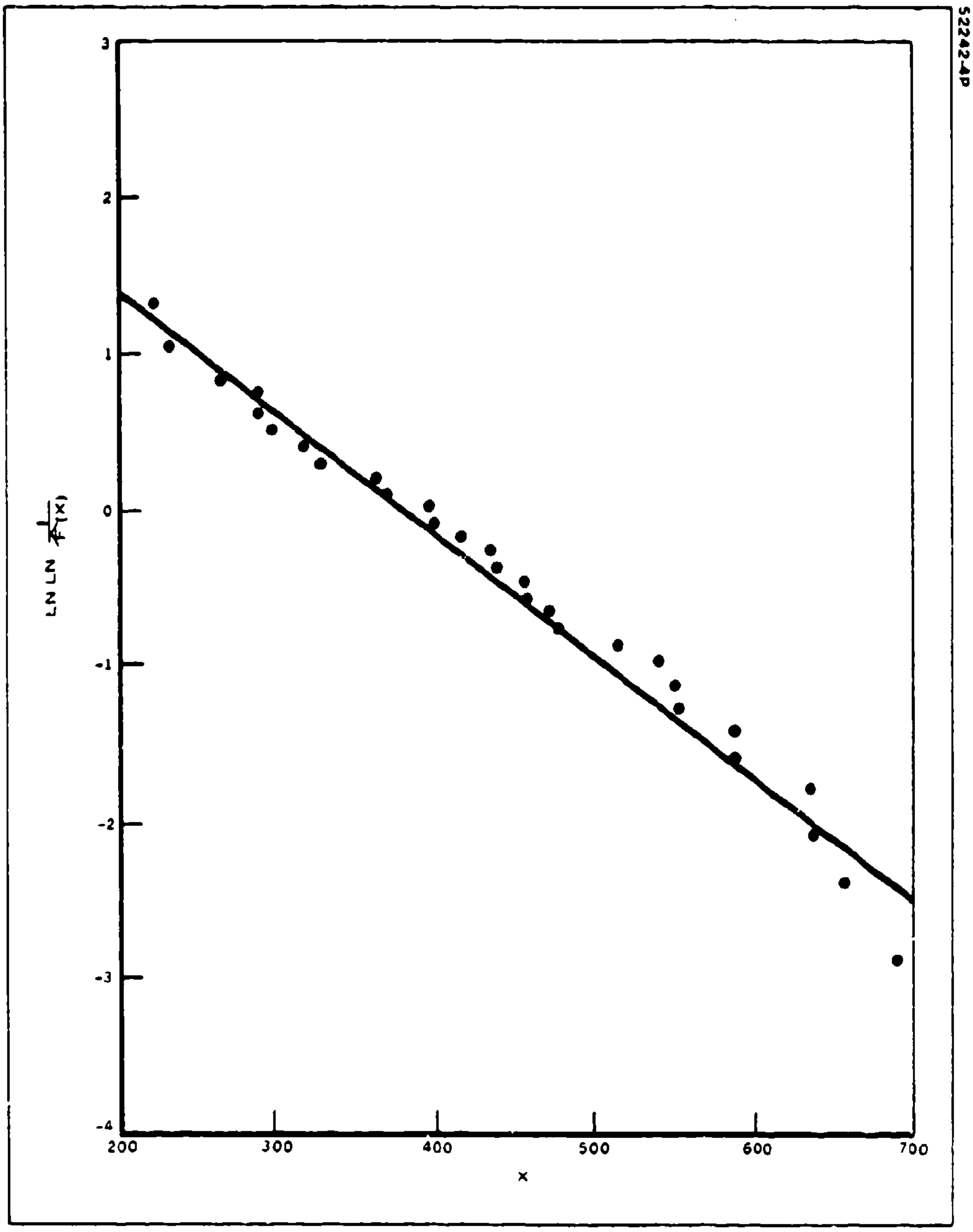

Figure 2.4.5. Plot of Fitted Straight Line for Use With the Extreme Value Distribution

3. Method

c. Perform the following calculations:

$$\hat{\nu} = \hat{\beta}(x-\hat{m})$$

$$c = \sqrt{\frac{6}{N\pi^2}}\, Z_{1-\alpha}$$

$$b = \frac{\pi^2}{6}$$

where

x = mission time
N = sample size
$Z_{1-\alpha}$ = $1-\alpha$ quantile of the standard normal distribution

d. Calculate a lower bound for ν^*

$$\nu^* = \frac{1}{1-c^2}\left(-.423c^2 + \hat{\nu} + c\sqrt{(\hat{\nu} + .423)^2 + (1-c^2)/b^2}\right)$$

e. Calculate a lower bound for reliability as follows:

$$R^* = 1 - \exp\left[-e^{-\nu^*}\right]$$

Examples

c. The calculations provide the following results:

$$\hat{\nu} = .0076(300-380) = -.6$$

$$Z_{1-.05} = 1.645$$

$$c = \sqrt{\frac{6}{30\pi^2}}(1.645) = .18$$

$$b = \frac{\pi^2}{6} = 1.64$$

d. $\nu^* = -.52$

e. The lower 95% confidence bound for reliability at 300 hours is

$$R^* = 1 - e^{-e^{-.52}}$$

$$R^* = .81$$

4. For Further Information

This example demonstrates the Largest Extreme Value Distribution. The method for the Smallest Extreme Value Distribution is essentially the same.

2.4.6 Tests for Increasing Failure Rate

2.4.6.1 Distribution Free Test

1. When to Use

When a number of failure times have been observed and the probability distribution is unknown this test may be used to determine if the observations are from a distribution with a decreasing, constant or increasing failure rate. The test is non-parametric and was originally proposed by M.G. Kendall (1938). The detailed method presented here is from the work of Henry Mann (1945), and from Barlow and Proschan (1964).

2. Conditions for Use

The observed failure times must be arranged in ascending order. A simple computer program will facilitate the calculations. Table A in Appendix II is used in conjunction with the calculations to define the values required to hypothesize whether the failure rate is decreasing constant or increasing.

3. Method / Examples

Method

a. Arrange the observed failure times (x_i's) in ascending order.

b. Compute T_i for each adjacent pair of failure times as follows:

$$T_1 = x_1$$

$$T_2 = x_2 - x_1$$

$$T_3 = x_3 - x_2$$

$$T_n = x_n - x_{n-1}$$

c. Compute D_i for each T_i as follows:

$$D_1 = nT_1$$

$$D_2 = (n-1)T_2$$

$$D_3 = (n-2)T_3$$

$$D_n = T_n$$

Examples

a. Given the following 8 failure times arranged in ascending order:

2,6,9,12,14,16,17,18

b. In this example, the T_i's are

$$T_1 = 2$$

$$T_2 = 6-2 = 4$$

$$T_3 = 9-6 = 3$$

$$T_4 = 12-9 = 3$$

$$T_5 = 14-12 = 2$$

$$T_6 = 16-14 = 2$$

$$T_7 = 17-16 = 1$$

$$T_8 = 18-17 = 1$$

c. The D_i's are

$$D_1 = 8 \cdot 2 = 16$$

$$D_2 = 7 \cdot 4 = 28$$

$$D_3 = 6 \cdot 3 = 18$$

$$D_4 = 5 \cdot 3 = 15$$

$$D_5 = 4 \cdot 2 = 8$$

$$D_6 = 3 \cdot 2 = 6$$

$$D_7 = 2 \cdot 1 = 2$$

$$D_8 = 1 \cdot 1 = 1$$

3. Method

d. Generate a V_{ij} statistic by comparing each set of two D_i's.

LET $V_{ij} = 1$ if $D_i > D_j$ for all

$i,j = 1,2 \ldots n$, with $i<j$

$V_{ij} = 0$ otherwise

e. Generate the test statistic

$$V_n = \sum_{i<j} V_{ij}$$

f. Now enter Table X of the Appendix with V_n and the desired level of significance.

Example

d. Since $n=8$, there will be $\binom{8}{2} = \frac{8!}{2!6!} = 28$ comparisons of D_1 through D_8 as follows:

$V_{12} = 0$, since $D_1 \Phi D_2 = 16<28$

$V_{13} = 0$, since $D_1 \Phi D_3 = 16<18$

$V_{14} = 1$, since $D_1 \Phi D_4 = 16>15$

In a similar manner the following V_{ij}'s are assigned values of 1 since $D_i > D_j$:

$V_{15}, V_{16}, V_{17}, V_{18}, V_{23}, V_{24}, V_{25},$

$V_{26}, V_{27}, V_{28}, V_{34}, V_{35}, V_{36}, V_{37},$

$V_{38}, V_{45}, V_{46}, V_{47}, V_{48}, V_{56}, V_{57},$

$V_{58}, V_{67}, V_{68}, V_{78}$

e. From step d

$$V_n = 26$$

f. Enter Table X of the Appendix with $n=8$ and an $\alpha=.10$ level of significance. Following across the row $n=8$, the closest value to .10 is .089 which corresponds to an observed V_n of 8. Therefore, if V_n had been from 0 to 8 it could have been concluded at a .089 level of significance that the failure rate was decreasing.

In this example it is desired to test for an increasing failure rate since $V_n = 26$.

Table X in the Appendix is symmetrical; therefore, an .089 level of significance corresponds

3. Method

Example

f. (Continued)

to $V_n = 20$. Since $V_n = 26 > 20$, it can be concluded that the failure rate is increasing.

4. For Further Information

For the full derivation of this method refer to "Nonparametric Tests Against Trend," Henry Mann, Econometrica, Vol. 13, 1945, and "Mathematical Theory of Reliability," by Barlow and Proschan, John Wiley & Sons, 1964, pp. 232-233.

For an example of the use of the method on empirical data, refer to RADC TR-66-425 "Accelerated Reliability Testing for Nonelectronic Parts," September 1966, AD 803 484.

The table from Mann's paper which is reproduced as Table X in Appendix II covers sample sizes up to n=10. Above n=10, tables of the standardized normal distribution can be used because Mann proved that V_n is asymptotically normally distributed with mean $\frac{n(n-1)}{4}$ and a variance of

$$\frac{2n^3 + 3n^2 - 5n}{72}.$$

2.4.6.2 Test Based on Probability Limits and Weibull Assumptions.

1. When to Use

When a set of part failure times has been generated and it is desired to test if the underlying distribution of failure times is exponential (β = Weibull shape parameter = 1). In effect, this becomes a form of goodness-of-fit test for deciding between the exponential and Weibull distributions.

2. Conditions for Use

a. The sample size must be greater than 5.

b. The $\hat{\beta}$ (estimate of Weibull shape parameter) must have been calculated from the empirical data by the maximum likelihood method of Section 2.4.2.1.2.

c. Table IX in Appendix II is required.

3. Method / Example

Method	Example
a. Observe and record part failure times.	a. Given the following 20 failures times

92	325	640	1010
130	420	700	1020
233	430	710	1280
260	465	770	1330
320	518	830	1690

Method	Example
b. Calculate the Weibull shape parameter by the maximum likelihood method of Section 2.4.2.1.2.	b. From this same data and from the example in Section 2.4.2.1.2 the Weibull shape parameter is 1.62.
c. Decide on the desired significance for the test for exponentiality.	c. For this example, it is desired to have 10% significance level for the hypothesis test (an arbitrary decision).
d. Enter Table IX with the sample size (N), the upper percentage points, and the lower percentage points of the probability interval.	d. Enter the table at N=20, γ_L=.95, γ_U=.05. The tabled values for a 90% probability interval are 0.690 and 1.264.
e. Compare the probability limits with the calculated value of ($\hat{\beta}$), the Weibull shape parameter. If $\gamma_L \leq \hat{\beta} \leq \gamma_U$, then it can be stated that β = 1 and hence, the data is from an exponential distribution.	e. Since $\hat{\beta}$ = 1.62 is not contained in the interval 0.690 - 1.264, then the hypothesis that $\hat{\beta}$ is from a distribution with β = 1 (exponential) cannot be supported. The alternate hypothesis is that the failure times were from a distribution with an increasing hazard rate, since $\hat{\beta}$ > 1.264.

4. For Further Information

The method presented here is from a paper by D.R. Thoman, L.J. Bain and C.E. Antle. The paper was titled "Inferences on the Parameters of the Weibull Distribution" and was published in Technometrics, Vol. 11, No. 3, August 1969, pp. 445-460.

2.4.7 Outlier Tests

2.4.7.1 Early Failures

1. When to Use

When an early failure is suspected not to belong to a population of failures which fits a particular failure distribution, this method may be

employed to determine if an early failure occurred too early to be included in the population.

2. Conditions for Use

a. There must be engineering justification for suspecting the early failure to be unrelated to the main group of failures. Such justification might be based upon a difference in failure modes for example.

b. Failure times must be collected.

c. A sample size of at least 20 in the main group is necessary.

3. Method

a. For an early suspect failure time x_o, compute $F(x_o)$, the cumulative distribution function, with parameters estimated from the main group of failure times only, evaluated at x_o.

b. Compute

$$p = (1 - F(x_o))^n$$

where

n = sample size of main group of failures.

c. If $p > 0.95$, omit the suspect failure time. It probably does not belong to the population determining the distribution of failure times.

Example

a. Consider a Weibull sample of size 20 with parameters, estimated from the 20 failure times by the method of Section 2.4.2.1.1.

$\hat{\beta} = 1.5$

$\hat{\alpha} = 2 \times 10^{10}$ cycles. To examine an early failure at 10^5 cycles, compute

$$F(10^5) = 1 - \exp\left(\frac{-10^5 \times 1.5}{2 \times 10^{10}}\right) = .00158$$

b. $p = (1 - .00158)^{20} = 0.969.$

c. Since $p = 0.969 > 0.95$, the early failure time does not belong to the population.

4. For Further Information

If $p \leq 0.95$, recalculate estimates for the parameters of F(x) with x_o included in the group.

2.4.7.2 Late Failures

1. When to Use

When a later failure is suspected not to belong to a population of failures which fits a particular failure distribution, this method may be employed to determine if a late failure occurred too late to be included in the population.

2. Conditions for Use

There must be engineering justification for suspecting the late failure to be unrelated to the main group of failures. Such justification might be based upon a difference in failure modes for example. A sample size of at least 20 in the main group is needed.

3. Method

a. For a late suspect failure time x_o, compute $F(x_o)$, the cumulative distribution function, with parameters estimated from the main group of failure times only, evaluated at x_o.

b. Compute

$$q = (F(x_o))^n$$

c. If $q > 0.95$, omit the suspect failure time. It does not belong to the population determining the distribution of failure times.

d. If $q \leq 0.95$, recalculate estimates for the parameters of $F(x)$ with x_o included in the group.

Example

a. Consider a Weibull sample of size 20 with parameters, estimated from the 20 failure times by the method of Section 2.4.2.1.1,

$$\hat{\beta} = 1.5$$

$$\hat{\alpha} = 2 \times 10^{10} \text{ cycles}$$

To examine a late failure at 2×10^7 cycles, compute

$$F(2\times10^7) = 1-\exp\left(\frac{-2\times10^{7\times1.5}}{2\times10^{10}}\right) = 0.988$$

b. $q = (0.958)^{20}$

$= 0.794$

c. $q = 0.794 \not> 0.95$

d. Since $q = 0.794 \leq 0.95$, the failure time 2×10^7 cycles does belong to the population. So, it is necessary to repeat the estimation of the Weibull distribution parameters β and α from Section 2.4.2.1.1 with $n = 21$ and the failure time 2×10^7 cycles included.

3.0 RELIABILITY SPECIFICATIONS

3.1 <u>Introduction</u>. The purpose of a reliability specification is to fix the reliability component of mission effectiveness by quantifying required reliability characteristics for the part, equipment, or system. In order to achieve this purpose the reliability specification must be stated in complete and unambiguous terms. A reliability demonstration test will verify whether or not the requirement is satisfied.

Ambiguous requirements may result in an item that passes the demonstration but is not effective with respect to the requirements, and vice versa. For example, to state that a part must have a life of 1000 hours is ambiguous. The intention of such a specification could be: to require all such parts to survive 1000 hours; to require all such parts to have a 1000 hour MTBF; to require 90% (on the average) of all such parts to have 1000 hours; or any number of requirements. Moreover, in an unambiguous statement, the true intention of the specification must be accurately stated. For example, if the reliability requirement is that a part must survive 100 hours with 90% probability it is often tempting to "convert" this requirement to an MTBF specification based on exponentially distributed lifetimes. For an exponential distribution an MTBF of 1000 hours is roughly equivalent to a 100 hour survival probability of .90 (since $\exp(-100/1000)=\exp(-.1)=.9048$). Specifying a 1000 hour MTBF would be approximately equivalent to the requirement in the exponential case. However, if lifetimes are actually Weibull distributed with survival function given by

$$\exp(-(t/308)^2),$$

then the mean of this distribution is only 273 hours, and yet the survival probability for 100 hours is

$$\exp(-(100/308)^2)=\exp(-.105)=.90$$

which satisfies the original requirement. Imposing the 1000 hour mean life would thus cause overdesign. Also, this part actually meets the reliability requirement of survival of 100 hours with .90 probability, but would probably fail the corresponding reliability demonstration test that is designed to a 1000 hour MTBF requirement.

Many of these difficulties are alleviated when the underlying life distribution is exponential. In this case, it is sufficient to specify mean life, and knowing the mean determines all other quantifiable reliability measures associated with the exponential distribution. The exponential distribution has been the life distribution of choice in the electronics industry because of compelling evidence (both empirical and theoretical) which makes it suitable for describing lifetimes for complex electronic units whose failure modes are not wear-out related. Consequently, much effort has been spent in developing and updating MIL-STD-781C, "Reliability Design Qualification and Production Acceptance Tests: Exponential Distribution." And, in view of the success of the exponential distribution in the analyses of section 2 of this notebook concerning its applicability to nonelectronic parts, in many cases specifying mean life will be adequate for nonelectronic parts as well.

In summary, reliability can be quantified in many ways: mean life, median life, probability of mission survival, etc. A reliability specification may be any one or more such quantities depending on the underlying reliability requirements, and/or life distribution. The reliability specification must accurately reflect the underlying reliability requirements, and be both semantically and quantitatively unambiguous.

3.2 Reliability Specification for the Exponential Distribution. The survival function (or reliability function) for the exponential distribution is $R(t)=\exp(-t/\theta)$, $t>0$, where θ is the mean life. The most direct way to specify any reliability requirement in the context of the exponential distribution is to convert the requirement to a requirement on mean life. The specification of mean life or, equivalently, MTBF, is particularly convenient in subsequent reliability demonstration test design since MIL-STD-781C is based on MTBF specifications. This, along with the fact that the exponential distribution is uniquely determined by the mean life (making MTBF an unambiguous specification) should establish MTBF as the best form of reliability specification. The following table presents formulae for converting various reliability requirements to MTBF in the exponential case.

RELIABILITY MEASURE	CORRESPONDING MTBF
Failure Rate	$\theta = 1/(\text{Failure Rate})$
Probability of survival for t hours = r	$\theta = -t/\ln(r)$
x(p) = the p quantile life (i.e. x(p) = the life beyond which the part will live with probability 1-p)	$\theta = -x(p)/\ln(1-p)$

The following examples should clarify these concepts.

Example 1.

The reliability requirement for an equipment is expressed as a failure rate of 250 failures per million hours. The corresponding MTBF requirement is $(1/250)(1,000,000)$ hours = 4000 hours.

Example 2.

The reliability requirement for an equipment is expressed as a probability of mission (= 1000 hours) survival of .99. The corresponding MTBF requirement is $-1000/\ln(.99) = 99,499$ hours.

Example 3.

The .10 quantile life requirement for an equipment is 1000 hours. The corresponding MTBF requirement is $-1000/\ln(1-.10) = 9,491$ hours.

In order to use MTBF specifications in a reliability demonstration test from MIL-STD-781C, it is necessary to specify the upper (acceptable) test MTBF (θ_0), the lower (unacceptable) test MTBF (θ_1), the producer's risk α, and the consumer's risk β. Further details may be found in MIL-STD-781C.

3.3 <u>Reliability Specification for the Weibull Distribution</u>. The two parameter Weibull survival function is given by

$$R(t) = \exp(-(t/b)^c), \; t > 0, \; b > 0, \; c > 0.$$

The parameter b is called the scale parameter (also, characteristic life), and the parameter c is called the shape parameter. The following table lists common reliability measures in terms of these parameters.

RELIABILITY MEASURE	FORMULA
Mean Life	$b\,\Gamma(1+1/c)$, where Γ is the usual Gamma function.
p quantile, x(p), i.e. the life beyond which the equipment will survive with probability 1-p.	$b(-\ln(1-p))^{1/c}$
Characteristic Life, i.e. x(.632)	b

Since the Weibull distribution is a two-parameter distribution, any unambiguous reliability specification must involve two quantities. For example, specifying (b,c) directly would be sufficient, although not much physical significance can be attached to the parameter c. Other specifications which would also be sufficient would be mean life and the .90 quantile life; the .50 and .90 quantiles; or characteristic life (b) and .95 quantile life. These possibilities are summarized in the following table.

RELIABILITY SPECIFICATION	CORRESPONDING VALUES OF (b,c)
Mean Life, θ, and p quantile x(p).	Must be found by iteratively solving: $\theta = b\,\Gamma(1+1/c)$ $x(p) = b(\ln(1/(1-p)))^{1/c}$

RELIABILITY SPECIFICATION	CORRESPONDING VALUES OF (b,c)
Two quantiles, x(p),x(q).	$c = \dfrac{\ln[\ln(1/\{1-q\})/\ln(1/\{1-p\})]}{\ln[x(q)/x(p)]}$ $b = \dfrac{x(p)}{[\ln(1/\{1-p\})]^{1/c}}$
Characteristic Life, b, and the quantile x(p).	b is the Characteristic Life $c = \dfrac{\ln[\ln(1/\{1-p\})]}{\ln[x(p)]-\ln(b)}$

It is not often practical to specify reliability in terms of the Weibull or any other two parameter distribution because the corresponding reliability demonstration test procedures are cumbersome. Moveover, since there are two parameters involved, there is no "OC curve" as in the case of MIL-STD-781C for the exponential distribution. Finally, and most importantly, there is no natural ordering of the parameter pairs (b,c). That is, given that "acceptable" values have been established for the parameters (b,c), there is no obvious logical way to assign "unacceptable" values to (b,c). For example, the pairs (b,c)=(308.6,2) and (b,c)=(212,3) both determine Weibull distributions having 100 hours as the .10 quantile. The respective mean lives are 273 hours, and 189 hours, so that the pair (b,c)=(308.6,2) appears more acceptable. However, the .05 quantiles for the pairs (b,c)=(308.6,2) and (b,c)=(212,3) are 69.9 hours and 78.8 hours, respectively. Thus, from this point of view, the pair (b,c)=(212,3) is more acceptable since 78.8 hours are survived with probability .95, whereas for the pair (b,c)=(308.6,2) only 69.9 hours are survived with probability .95.

One way to alleviate this problem is to fix one parameter for all cases. This is the same as assuming that one parameter, either b or c, is known exactly. Since neither b nor c is ever known exactly in practice, this is an unacceptable solution.

3.4 <u>Reliability Specification Without Respect to a Particular Underlying Life Distribution.</u> In many instances, there is no evidence to suggest a feasible parametric (e.g. exponential, Weibull) life distribution for the equipment on which reliability is to be specified. Also, it is often the case that when a two-parameter life distribution is appropriate, the reliability requirement is only sufficient to determine one of the parameters. Moreover, in a two-parameter model, it is not always clear how to specify acceptable values for the parameters versus unacceptable values even when the reliability requirements are sufficient to determine both parameters.

When these situations arise, there is a type of reliability specification which can be used in conjunction with reliability demonstration tests which do not assume any particular underlying parametric life distribution (so-called nonparametric tests). These specifications are life distribution quantiles.

This type of specifica ion has already been discussed in the sections on reliability specification for the exponential distribution. There, however, it was suggested that these quantiles be used to compute corresponding MTBFs to facilitate the use of MIL-STD-781C. The p quantile of the life distribution (denoted by x(p)) is the life beyond which the equipment will live with probability 1-p. [illegible] antile x(p) can be specified directly, or indirectly, by specifying the probability of survival for a fixed time period. For example, specifying that with .90 probability the equipment shall survive 1000 hours is equivalent to stating that the .10 quantile of the life distribution shall be 1000 hours, i.e. x(.10)=1000 hours. In many cases, it is of interest to place some requirement on some measure of central tendency of the life distribution, e.g. mean life. While mean life does not lend itself to nonparametric demonstration tests, median life does, since median life is x(.50), the .50 quantile of the life distribution. Indeed, when mean life is specified, the reliability engineer is often (mistakenly, in general) thinking of median life, i.e. that life beyond which 50% of the equipments will survive, on the average.

The following table summarizes the strategy for specfying reliability in cases where no particular underlying parametric life distribution is assumed. These types of specifications can be used directly in the nonparametric test plan discussed in section 5.

RELIABILITY SPECIFICATION	WHEN TO USE
x(.50), the median life.	Requirements concern a measure of central tendancy of the life distribution.
The probability of surviving a fixed time T.	Requirements concern a particular mission length T which the equipment must survive with high probability.
x(p), $0 < p < .5$.	See above.

4.0 SPECIAL APPLICATION METHODS FOR RELIABILITY PREDICTION

4.1 Introduction. This section is concerned with the estimation of reliability of mechanical and electromechanical components in service. We are not concerned herein with the classical estimation problems faced by statisticians which are described in Section 2 but with practical examples where the engineer is required to create an estimate of reliability from whatever data he can find. The methods described in this section involve the use of "engineering experience" or judgment to extend what is usually meager sampling information to obtain meaningful comparisons of materials, designs, and environments.
It is only through the application of engineering judgment to available data that an estimate of reliability in service can be created. The consequence of such methods will of necessity be a point estimate rather than an interval estimate because the probability distribution of the estimator cannot be obtained.

4.2 Background for Reliability Prediction Model Development. Nonelectronic components have numerous failure modes as compared to electronic components. Some of the more basic failure modes which affect this class of components are fatigue, creep, impact, thermal shock, corrosion, oxidation, fretting-corrosion, elastic deformation, relaxation, lubrication failure, wear, spalling, erosion, leakage, delamination, buckling, and radiation damage. Detailed discussion of these failure modes may be found in ASME (1965). In a proper reliability assessment the dominant mechanisms must be identified and considered since each mechanism represents a competing failure risk with its own failure distribution.

Several possible approaches are available for the model development, each of which has definite merit but is also subject to limiting constraints.

One approach is through the analysis of accelerated life test results. This approach presupposes that a large number of devices has been tested or is currently being tested in combinations representing the various technologies, processes, etc. The results of such controlled tests would provide some indication of the characteristics and peculiarities of the devices as a function of the several configurations, stresses and applications included in the test design. However, the extrapolation of these accelerated test results to more normal operating conditions would be open to questions of validity due to the uncertainties regarding the extrapolation algorithm. Further, while test data under controlled accelerated conditions should aid in understanding the reliability characteristics, it is difficult to obtain data that covers the wide range of technologies and stress conditions that would be necessary in order to place major dependence on this approach alone.

An alternate approach involves the development of a reliability model and its parameters based on a knowledge of fabrication techniques and the anticipated failure modes. Also required by this approach is a thorough understanding of the fundamental physical/metallurgical/chemical/electrical degradation mechanisms involved, as well as the proportionate weighting of these mechanisms in translating to the various configurations the component may assume.

A third approach would be to rely solely on the collection and reduction of empirical operating data where the pertinent information with respect to the model parameters would be extracted using suitable statistical techniques. This approach should provide optimal applicability since the field data reflect the actual reliability experience of the devices operating in their use environment. However, it requires the collection and reduction of a large database on the entire range of device configurations and application environments in order to evaluate each of the critical factors. In some cases, particularly with new devices, the amount of data needed to provide sufficiently accurate results may not be available.

The best approach endeavors to utilize the collective data and knowledge offered by all three approaches and subject it to careful, analytical scrutiny to censor out conflicting and discrepant information. This approach includes the following tasks: a literature review to define the component, equipment and environmental attributes which will be considered during model development, derivation of the preliminary model form, data collection, data reduction and analysis, development of the model parameters, and model refinement and verification.

Regardless of the approach taken, the derived model should have the following attributes:

- verified accuracy over the total range of all factors considered
- an uncomplicated approach using easily accessible information on component characteristics and environmental parameters
- dynamic, flexible expression, easily modified to accommodate new techniques
- appropriate discrimination against design and usage attributes which may degrade reliability

The simultaneous attainment of all of the above objectives is difficult, if not impossible. Often these goals are contradictory or mutually exclusive. As an example, some years ago a prediction model was proposed for microcircuits which possessed commendable accuracy over the range of parameters and was based on sound theoretical considerations. Unfortunately, to use the model, the engineer was required to input such information as metallization area, total diffusion area and other such fabrication/design information. Since this information was not available on vendor specification sheets and indeed was often vendor-proprietary, the model proved to be useless. Modifying the model to use more generic but readily available device parameters degraded the accuracy of the model. The overall utility of the model, however, was enhanced. A discussion of modeling and model limitations can be found in Flint et. al. (1982).

In reviewing the literature it becomes obvious that an abundance of models have been advanced for use in the prediction of nonelectronic component reliability. Unfortunately, most have been found to be deficient in one or

more of the areas below and as a consequence cannot be included in this section:

- Not application-oriented
- Not yet "engineer-ready"
- Not verified
- Single-vendor specific
- Requires information not easily available

4.3 Graphical Approaches to Reliability Prediction. The graphical approach discussed below briefly provides a means of translating meager information into a reliability estimate.

The information is most likely vendor supplied and thus may be optimistic, based on limited test data, or in the worst case represents a design objective. For these reasons, unless prior experience dictates otherwise, assumptions must be conservative in nature. For example, if an L_{10} (life time beyond which 90% survive) supplied by the vendor is based on small sample tests or if the vendor is unwilling to discuss the matter, the L_{10} life should be reduced by one-half as a minimum.

The ambiguity regarding life frequently must be clarified. Life may mean average, median, some period of time/cycles by which some percent will fail on the average, or the time to first failure among a population.

Weibull probability paper is a most useful tool available when the use of a graphical solution is necessary. When the shape or slope parameter, β, is equal to one, the distribution reduces to the exponential; an approximation of the lognormal distribution results from values of β in the range of 1.5 - 3, and the normal distribution approximation results from a β value of 3.5. With an estimate of some percentile of life, an assumption of the value of β, and the use of Weibull paper, the probability of failure before time x, say F(x), and the reliability, 1 - F(x), for any lifetime can be determined.

In those cases when a failure rate must be used in a prediction, it must be remembered that only for the special case of the exponential distribution, i.e., $\beta = 1$, will the failure rate be constant with all other values of β greater than one resulting in an increasing failure rate. In the latter case an average failure rate over a stated time period may be calculated employing the average cumulative hazard function, H(t). The expression is (assuming $1-F(x) = \exp\{-(x/\alpha)^{\beta}\}$):

$$\bar{H}(t) = \frac{t^{\beta-1}}{\alpha^{\beta}}. \qquad \text{(Wilson, et. al (1977).}$$

Alternate notation for $\overline{H}(t)$ is $\overline{\lambda}(t)$.

4.4 General Theory of Interference. When the strength of a component is less than the stress imposed on it, a failure can be expected to occur. Strength is the ability of a component to resist failure when subjected to stress. Stress or load may be defined as a mechanical load, dimensional variation, environment, temperature, etc. Since both strength and stress are variables, they may be described by probability distributions.

The strength of nominally identical components can be expected to vary due to variations in materials, dimensions, treatments, surface conditions, and so on. This variability can be described by a distribution function. Various approaches to estimating the strength distribution function are given in Bompass-Smith (1969), Burns (1975), Konno et. al. (1975), ASME (1965), Nilsson (1975), Thomas et. al. (1975), and Welker et. al. (1975). Most typically, however, so little will be known that both the form of the distribution and the variability about the mean will have to be assumed. Unless experience dictates otherwise, the strength variable is often assumed to be normally distributed with standard deviation equal to 5 - 15 percent of the normal value (Fulton, 1983).

The distribution of operational stresses can only be known to a reasonable certainty when the response of a reasonable number of prototypes to the full spectrum of operating conditions has been closely observed. Due to such constraints as time, cost, etc., the distribution of stress cannot be established and assumptions must be made. Further information regarding the estimation of the stress distribution may be found in Kececioglu et. al. (1964, 1967), and Fiderer (1976).

If the expected distributions of stress and strength can be estimated for a component then by employing interference theory the probability of failure of the component can be calculated. The concept is presented in detail in Kececioglu et. al. (1964), Disney et. al. (1968), Lipson et. al. (1973), Kapur et. al. (1977), Kececioglu (1972, 1974, 1977, 1968), Kececioglu et. al. (1974), and Dhillon (1980, 1981).

The mathematical foundations of Interference Theory may be outlined as follows. It is assumed that the stress is a random variable X having probability density function f_x and that the strength is a random variable Y having probability density f_Y. It is generally assumed that X and Y are statistically independent (although this assumption is not strictly necessary). The probability of failure, p(f), is then

$$p(f) = P \left\{ X > Y \right\} ,$$

i.e. the probability of failure is the probability that the stress exceeds the strength. An expression may be derived for p(f) as follows.

$$p(f) = P \left\{ X > Y \right\} = \int_{-\infty}^{\infty} \int_{y}^{\infty} f_X(x)\, f_Y(y)\, dx\,dy$$

$$= \int_{-\infty}^{\infty} f_Y(y) \quad (1 - F_X(y))\, dy$$

where

$$F_X(y) = \int_{-\infty}^{y} f_X(x)\, dx$$

is the cumulative distribution of the random variable X. Thus, the probability of failure is the area beneath the curve $f_Y(y)\ (1 - F_X(y))$ as y varies over all real numbers. Intuitively, $(1-F_X(y))\ f_Y(y)\ dy$ is the probability that the strength is in the infinitesimal interval (y, y+dy), and that the stress exceeds y. Integrating (or "summing") over all y then gives the total probability that stress exceeds strength.

The area under the curve $f_Y(y)\ (1 - F_X(y))$ is often referred to as the "interference zone." When the two densities f_X and f_Y coincide (i.e. are exactly equal), the probability of failure is exactly 1/2, although this is by no means the maximum value possible. In fact, when f_X is the normal density with mean μ_X and variance σ_X^2, and f_Y is the normal density with mean μ_Y and variance σ_Y^2, then it can be shown that

$$p(f) = \Phi \left(\frac{\mu_X - \mu_Y}{\sqrt{\sigma_X^2 + \sigma_Y^2}} \right)$$

where

$$\Phi\ (u) = \left(\sqrt{2\pi}\right)^{-1} \int_{-\infty}^{u} e^{-t^2/2}\, dt$$

is the standard normal cumulative distribution function. Hence, for example,

(1) $p(f) = 1/2$, if $\mu_X = \mu_Y$;

(2) $p(f) \rightarrow 1$, as $\mu_X \rightarrow +\infty$, μ_Y fixed;

(3) $p(f) \rightarrow 0$, as $\mu_Y \rightarrow +\infty$, μ_X fixed;

Thus, p(f) can take any value between zero and one. The explanation of (1) above is that when the mean stress equals the mean strength, it is equally likely for stress to exceed strength and vice-versa. In (2) above, when the mean stress is very large with respect to mean strength, the probability of failure is close to one. In (3) above, when the mean stress is very small with respect to strength, the probability of failure is very small.

The concept of interference is shown in Figure 4.4-1 where the interference zone is given as the shaded area. This illustrates the simple case where the strength distribution remains unchanged across time, i.e., is not affected by exposure to the failure causal stress distribution. Figure 4.4-2(a) and (b) illustrates the case where the strength distribution degrades as a function of time exposure to stress as the result of such failure mechanisms as fatigue, corrosion, and wear. Whether this time shift must be considered or may be dismissed depends of course on the rate of change expected. For example, in a naval environment corrosion is a rapid failure causal mechanism and the effect on the strength distribution must be considered; on the other hand, in most military ground fixed applications corrosion is a weak failure causal mechanism and the effect on the strength distribution may be ignored.

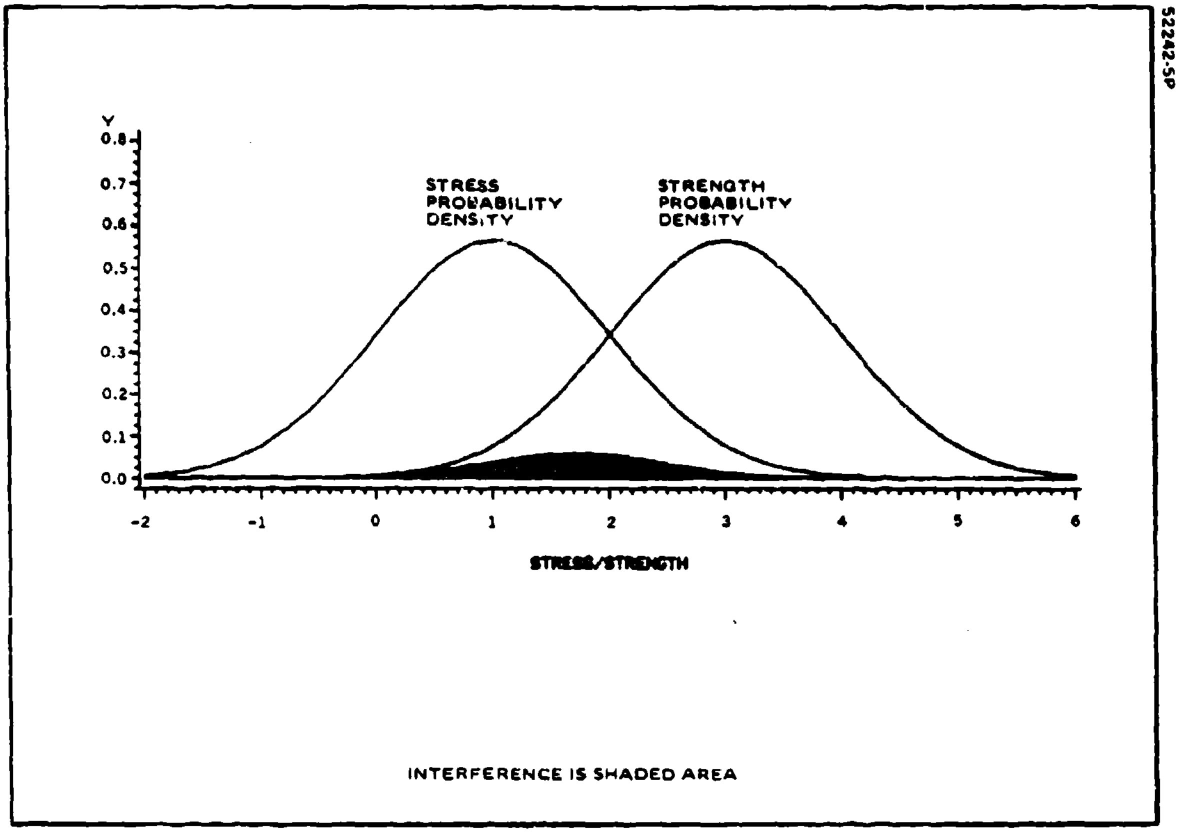

Figure 4.4-1. Illustration of the Concept of Interference

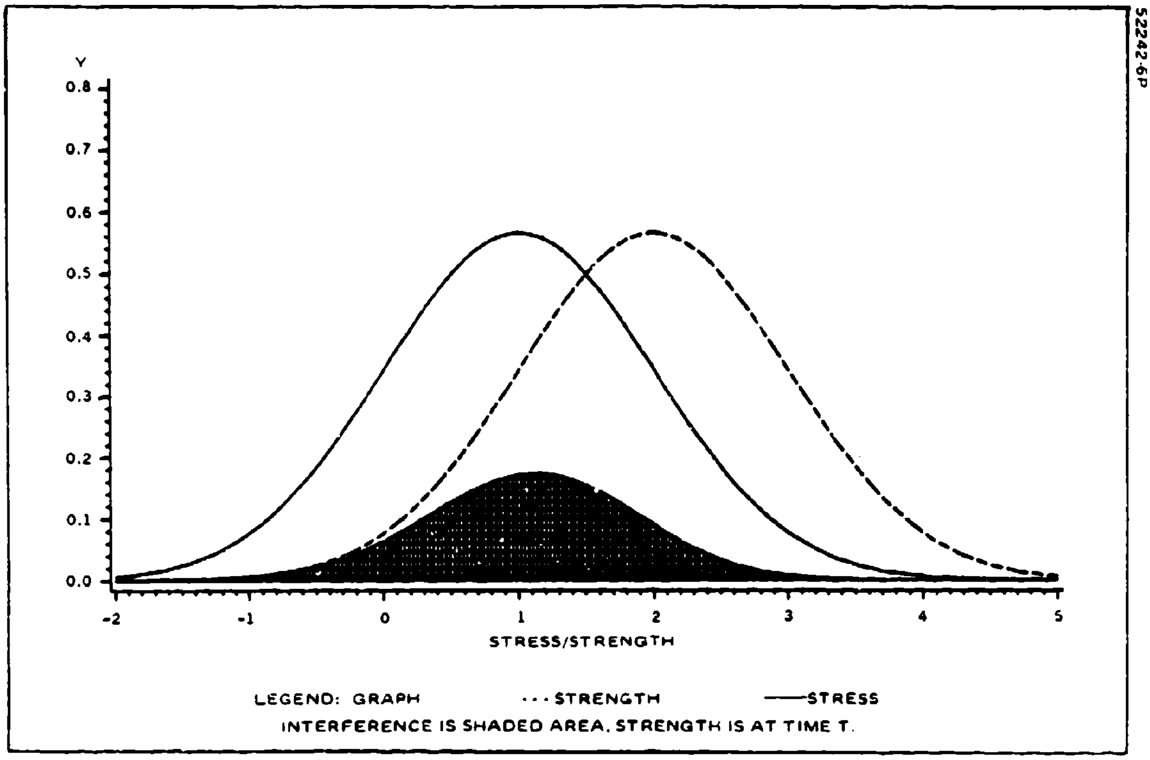

Figure 4.4-2(A) Time Varying Strength Density

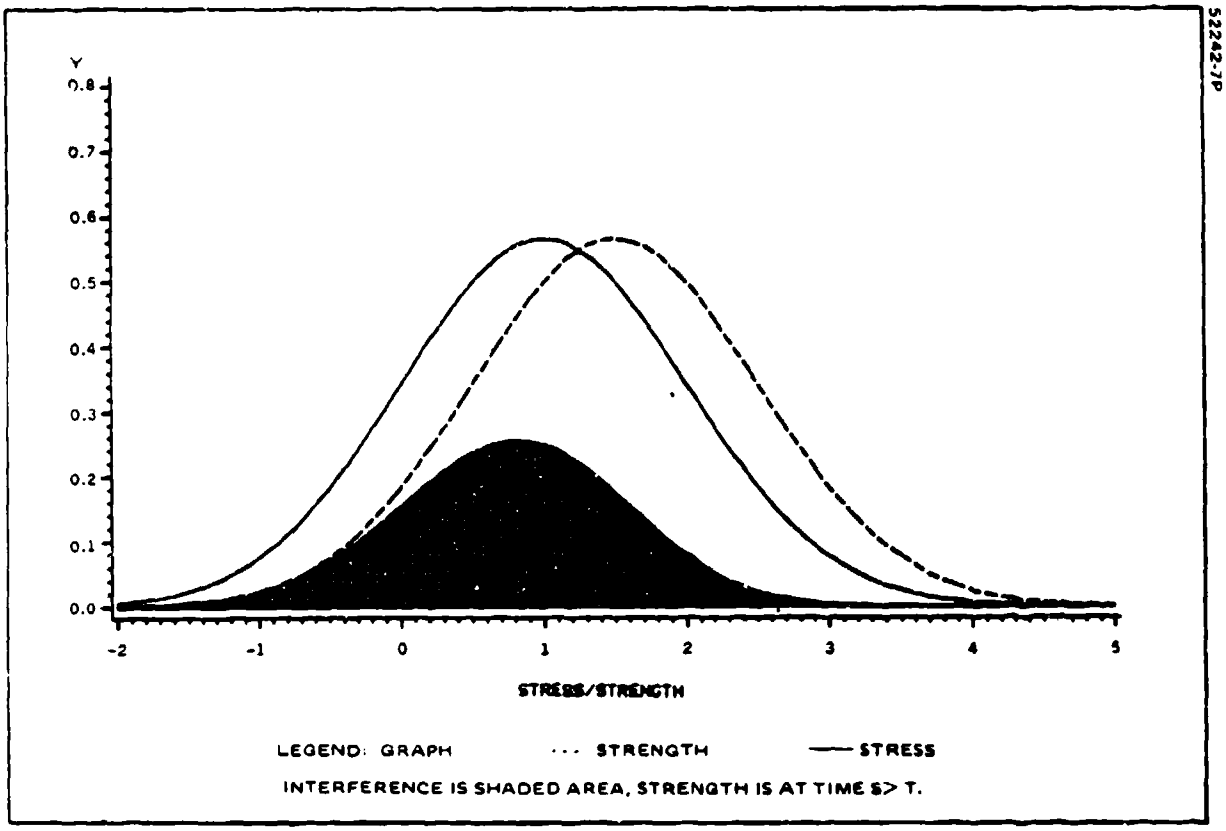

Figure 4.4-2(B) Time Varying Strength Density

4.5 Applications of Interference Theory to Reliability Prediction Methodology

Source: RADC-TR-66-710 (March, 1967) by Charles Lipson et. al., entitled "Reliability Prediction-Mechanical Stress/Strength Interference Models."

RADC-TR-68-403 (December, 1968) by Charles Lipson et. al., entitled "Reliability Prediction-Mechanical Stress/Strength Interference (Nonferrous)."

4.5.1 Purpose. The purpose of this method is to obtain a point estimate of reliability in service for mechanical components subject to fatigue failure. The method is applicable to:

a) Components subjected to completely reversed cyclic bending from axial, or torsion loads.

b) Components subjected to a combination of static and cyclic loads.

4.5.2 Description of Method. Given that strength and service stress each have a probability distribution of known type, and that the parameters of the two distributions are known, the probability that a random observation from the strength distribution exceeds a random observation from the stress distribution is equal to the reliability. The term "interference" is used to designate an occurrence where stress exceeds strength, so that reliability is the probability of no interference.

The source documents provide extensive tables giving the probability of failure as a function of the parameters for the following combinations of distributions:

Strength Distribution	Stress Distribution
Weibull	Normal
Weibull	Weibull
Normal	Normal
Largest Extreme Value	Normal
Smallest Extreme Value	Normal

These tables are perfectly general, and may be used for other types of failure than fatigue. However, the two reports tabulate parameters for fatigue failure only. Nonstandard symbols for the parameters are used in these tables. Table 4.5.1 shows their relationship with generally accepted symbols.

Several tables have been compiled in the source documents giving fatigue strength parameters for virtually all of the common ferrous, nonferrous, and light metal alloys, subjected to completely reversed bending or axial stresses. Included are the effect of heat treatment, surface finish, stress concentrators, temperature, and frequency.

TABLE 4.5.1. PARAMETERS OF TABULATED PROBABILITY DISTRIBUTIONS AS USED IN RADC-TR-68-403 (LIPSON, et. al. 1968)

1. Weibull Distribution:

$$R(x) = \exp\left[-\left(\frac{x - x_o}{\theta - x_o}\right)^b\right] \qquad x_o < x < \infty$$

x is the variable

3 parameters $\begin{cases} x_o \text{ is the lower bound of } x \\ \theta \text{ is the characteristic strength} \\ b \text{ is the slope parameter} \end{cases}$

This compares with the usual 3-parameter Weibull distribution

$$R(x) = \exp\left[-\frac{(x-\gamma)^\beta}{\alpha}\right] \qquad \gamma < x < \infty$$

as follows:

$\gamma = x_o$

$\beta = b$

$\alpha = (\theta - x_o)^b$.

2. Normal Distribution:

The unit normal deviate is characterized as

$$z = \frac{x - \mu}{\sigma}$$

which agrees with standard notation.

3. Extreme Value Distribution

For the Smallest Extreme Value (S.E.V.) distribution,

$$R(x) = \exp\left[-e^{\beta(x-M)}\right] \quad , \quad -\infty < x < \infty$$

x is the variable

2 parameters $\begin{cases} \beta^{-1} \text{ is the scale parameter} \\ M \text{ is the location parameter .} \end{cases}$

TABLE 4.5.1. PARAMETERS OF TABULATED PROBABILITY DISTRIBUTIONS AS USED IN RADC-TR-68-403 (LIPSON, et. al. 1968) (Continued)

This compares with the usual 2-parameter S.E.V. distribution,

$$R(x) = \exp\left[-e^{\alpha(x-\mu)}\right],$$

as follows:

$$\alpha = \beta$$

$$\mu = M .$$

For the Largest Extreme Value distribution, the same relationship holds, where

$$R(x) = 1 - \exp\left[-e^{-\beta(x-M)}\right].$$

Note: in 1), 2) and 3) above, R(x) is the reliability function.

The procedure for estimating reliability using the interference method takes several forms depending upon the assumptions made regarding the strength distribution and the stress distribution. The various methods are illustrated with numerical examples in the source documents.

4.6 Application of Interference Theory for Normally Distributed Strength and Normally Distributed Stress

Source: (1) Fiderer, Leo, "Design For Reliability in Hostile Environment," Microelectronics and Reliability, Vol. 15, Supplement, Pergamon Press, 1976, pp. 75-85.

(2) Lipson, Charles, Statistical Design and Analysis of Engineering Experiments, McGraw-Hill, 1973.

4.6.1 Purpose of the Method. To obtain a point estimate of reliability in service for non-electronic components. The method may be applied to a diverse number of failure causal factors.

4.6.2 Description of the Method. The description of interference of stress and strength distributions given in 4.4 applies equally to this method. The difference lies in the assumption that the random variables, which may take various distribution forms, may be approximated by a normal distribution so that in practical calculations normal distributions may be assumed without excessive error.

The steps involved in the procedure are as follows:

(1) Estimate the mean, μ_L, and standard deviation, σ_L of the load, L, and μ_s and σ_s of the strength, S.

Where there is no information available to estimate σ_L or σ_s a value may be assumed from the interval $.05\mu$ - $.15\mu$. Where the part is critical or a high reliability requirements exists, a worse-case approach should be taken, i.e., in the range of $.10\mu$ to $.15\mu$. For most conditions σ may be taken as $.09\mu$.

(2) Define the difference between strength and load as a new random variable D:

$$D = S - L,$$

with mean $\mu_D = \mu_s - \mu_L$,

and

standard deviation $\sigma_D = \sqrt{\sigma_s^2 + \sigma_L^2}$.

(3) The probability of failure, P(f), is found by computing:

$$P(f) = P\left\{ D < 0 \right\} = P\left\{ S-L < 0 \right\}$$

$$= P\left\{ \frac{D-\mu_D}{\sigma_D} < \frac{-\mu_D}{\sigma_D} \right\}$$

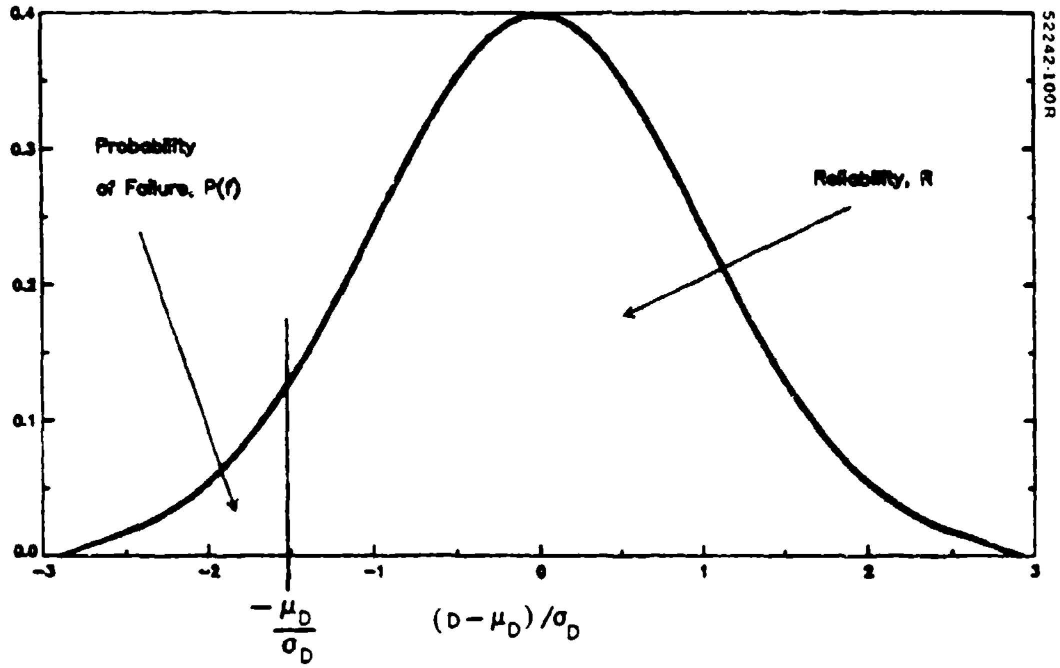

Figure 4.6.2-1.
Normalized Density Function of Excess Strength Over Load.

$$= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-\mu_D/\sigma_D} \exp \{ -t^2/2 \} \, dt.$$

Thus, P(f) is found by entering a table of the cumulative distribution function of a standard normal random variable with the value $-\mu_D/\sigma_D$. See figure 4.6.2-1.

(4) The reliability R is then

$$R = 1-P(f).$$

4.6.3 Examples

4.6.3.1 Shaft and Bushing Reliability. The reliability of a shaft and a bushing after ten years exposure (in a nonoperating state) to a heavy industrial environment is to be determined, i.e., the ability of the shaft to rotate without drag.

The dominant failure mechanism is considered to be corrosion. Information on corrosion rates and corrosion product build-up is available from the Battelle operated Metals and Ceramics Information Center.

In the analysis it will be assumed that the part dimensional variability is normally distributed and that the maximum and minimum allowable dimensions may be taken as the upper and lower three sigma points, respectively.

Part Specifications

Shaft - Stainless Steel
Dia. .123 - .124
Corrosion Rate 3.5×10^{-5} in/year loss
Corrosion Products 7×10^{-5} in/year buildup
Net Gain 3.5×10^{-5} in/year

Bushing - Aluminum Chromated
I.D. .125 - .127 in.
Corrosion Rate 6×10^{-5} in/year loss
Corrosion Products 7.8×10^{-5} in/year buildup
Net Gain 1.8×10^{-5} in/year

The maximum and minimum diameter 3σ points after ten years based on the buildup of corrosion products are:

Shaft

$$\text{Max } 3\sigma_s = .124 + 3.5 \times 10^{-5} \times 10 \times 2 = .1247$$
$$\text{Min } 3\sigma_s = .123 + 3.5 \times 10^{-5} \times 10 \times 2 = .1237$$
$$6\sigma_s = .1247 - .1237 = .001$$
$$\sigma_s = \frac{.001}{6}$$
$$\mu_s = .1242$$

Bushing $\quad \text{Max } 3\sigma_B = .128 + 1.8 \times 10^{-5} \times 10 \times 2 = .12764$

$\text{Min } 3\sigma_B = .125 + 1.8 \times 10^{-5} \times 10 \times 2 = .12464$

$6\sigma_B = .12764 - .12464 = .003$

$$\sigma_B = \frac{.003}{6}$$

$\mu_B = .12614$

The unreliability or probability of failure, p(f), is evaluated by establishing a new random variable D:

$$D = B - S$$

with mean $\mu_D = \mu_B - \mu_s = .00194$

and standard deviation $\sigma_D = \sqrt{\sigma_B^{\ 2} + \sigma_L^{\ 2}} = 5.27 \times 10^{-4}$

Thus, $\quad P\ (f) = P \left| \ D < 0 \ \right| = P \ \left| (D-\mu_D)/\sigma_D < -\mu_D/\sigma_D \right|$

$$= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-\mu_D/\sigma_D} \exp \ \left| -t^2/2 \right| \ dt.$$

From a table of the standard normal cumulative distribution entered at $-\mu_D/\sigma_D = -.00194/(5.27\times10^{-4})$ -3.68, it follows that

$$P(f) = 0.0001$$

and the reliability is:

$$R = 1-P(f) = .9999.$$

4.6.3.2 <u>Lifting Eye Reliability</u>. A lifting eye intended to be used in lifting shipboard equipment while the ship is at sea has a nominal strength of 60,000 lbs. The dead weight load is 12,000 lbs. This is all the information available to the reliability analyst.

It will be assumed that both the strength and load can be represented by normal distributions and that the nominal strength and load are the means of the distributions.

$$\mu_s = 60,000 \qquad\qquad \mu_L = 12,000$$

The variability of the tensile strength should be controllable such that the standard deviation may be assumed to be eight percent of the mean strength. However, the load due to the dynamics of wave/ship action may be quite variable. Thus, the load standard deviation will be assumed to be twenty percent of the mean load.

$$\sigma_s = .08\mu_s = 4,800 \qquad \sigma_L = .2\mu_L = 2,400$$

The probability of failure is evaluated by forming the new random variable:

$$D = S - L$$

where

$$\mu_D = \mu_s - \mu_L = 48{,}000, \text{ and } \sigma_D = \sqrt{\sigma_s^{\,2} + \sigma_L^{\,2}} = 5366.$$

thus,

$$p(f) = P\left\{D < 0\right\} = P\left\{\frac{D-\mu_D}{\sigma_D} < \frac{-\mu_D}{\sigma_D}\right\} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-\mu_D/\sigma_D} \exp\left\{-t^2/2\right\} dt$$

where

$$-\mu_D/\sigma_D = -48000/5366 = -8.9.$$

From a table of the standard normal cumulative distribution function the value of P(f) is approximately 0.

Thus the reliability is

$$R = 1 - P(f) = 1.$$

4.6.3.3 Diaphragm Reliability. Calculate the reliability of a diaphragm intended to be used in a one-shot device. Each diaphragm must pass 5 cycles of a worst-case pressure-time profile proof test as acceptance criteria. The purchaser has specified the lower 3 sigma point to be 5 test cycles.

A small sample size population has been tested to failure which resulted in an estimate of a mean lifetime of 11.44 proof tests. The sample size was not large enough to prove the lifetimes to be normally distributed.

It will be assumed that the proof test lifetimes of the production population will be normally distributed with a mean of 11.44 test times and a σ of 2.147.

Denoting by L the lifetime in proof tests of the diaphragm, and noting that this is a one-shot device and therefore the diaphragm needs only to survive one test, it follows that the probability of failure is

$P(f) = P\left\{L < 1\right\} = P\left\{\frac{L-\mu}{\sigma} < \frac{1-\mu}{\sigma}\right\}$ where $\frac{1-\mu}{\sigma} = (1 - 11.44)/2.147 = -4.86$. Referring to a table of the standard normal cumulative distribution function, it follows that

$$P(f) = .000000605$$

and then

$$R = 1 - P(f) = .999999395$$

4.7 Application of the Average Failure Rate Method for Grease Lubricated Rolling Element Bearings

Source: Wilson, D.S., and Smith, R., "Electric Motor Reliability Model," RADC-TR-77-408, December, 1977 (AD 050179).

4.7.1 Purpose of Method. To obtain an estimate of the average failure rate of grease lubricated rolling element bearings over a related time period.

4.7.2 Description of Method. The method consists of an empirical mathematical model which provides an estimate of the Weibull characteristic life, α, and was developed through the use of regression analysis and a large data base. Essential tables are provided.

The average failure rate is obtained by averaging the Weibull cumulative hazard function over the time period of interest.

A modification has been made in the characteristic life model so that it is valid for a single bearing rather than for a population of first failures of pairs of bearings as given in the source. The method employed is given in Ang (1970) under Suspended Item Tests.

The characteristic life model is based primarily on the effect of temperature on the lubrication qualities of grease and such secondary effects as quality, bore size, speed, grease, and load. The consideration of load as a secondary factor is consistent with good design practice which limits the loads on grease-lubricated bearings to 15 percent or less of rated load capacity.

The models are as follows:

$$\bar{\lambda}_t = \frac{t^{1.878}}{\alpha_B^{2.878}} \qquad (1)$$

$$\alpha_B = \frac{1.241}{\dfrac{1}{10^{\left[\frac{2342}{T} + q - 4.32\ DN\times10^{-6} + Kg - .001N\left(\frac{W}{SP}\right)^{1.5}\right]}} + \dfrac{1}{10^{\left[\frac{-4760}{T} + 19.7\right]} + 300}}$$

where

t = time for which failure rate is required (in hours)

α_B = bearing characteristic life (in hours)

q = quality factor

DN = bearing bore (mm) x speed (RPM)

T = bearing operating temperature (degrees Kelvin)

K_g = grease constant

N = RPM

W = load in pounds

SP = Specific dynamic capacity at 33 1/3 RPM in pounds

TABLE 4.7.1. QUALITY FACTORS

Military Specification	.12
Commercial	-.27

TABLE 4.7.2. K_g GREASE CONSTANT

Source	Oil	Thickener	MIL-Spec.	Max. T°C	K_g
1	Diester	Sodium and Solid Lubricant	MIL-G-3278A	170	1.35
2	Diester	Lithium	MIL-G-3278A	120	1.55
3	Silicone	Lithium	- - - -	150	1.74
4	Mineral	Sodium	MIL-G-18709A	150	1.41
5	Silicon	Lithium	MIL-L-15719A	177	1.81
6	Synthetic Hydrocarbon	Non-soap	MIL-G-81322	170	1.74

4.7.3 Examples

Example 1

Determine the average failure rate of a bearing with the following specifications for an operating period of 10,000 hours.

Military quality

Grease 5

Bore Dia. 13 mm

Bearing Operating Temp. 30°C

Speed 3600 RPM

Load 10 lbs

Specific Dynamic Capacity 505 lb (from bearing manufacturer's catalog)

Then:

q (quality factor) = .12 (Table 4.7.1)

K_g (grease constant) = 1.81 (Table 4.7.2)

DN = Bore D x speed = 13 x 3600 = 46800

T = 30 + 273 = 303°K

Using Eq. 2

$$\alpha_B = \frac{1.241}{\dfrac{1}{10^{\left[\frac{2342}{303} + .12 - 4.32 \times 4680\times10^{-6} - 1.81 - .001\times3600\left(\frac{10}{505}\right)^{1.5}\right]}} + \dfrac{1}{10^{\left[\frac{-4760}{303} + 19.7\right]} + 300}}$$

$$= \frac{1.241}{\dfrac{1}{10^{6.009}} + \dfrac{1}{10^{3.990} + 300}}$$

$$= \frac{1.241}{9.8 \times 10^{-7} + 9.928 \times 10^{-5}}$$

= 12378 hrs.

Using Eq. 1

$$\bar{\lambda}_{10,000} = \frac{(10,000)^{1.878}}{(12378)^{2.878}} = .000054$$

or 54 failures per million hours.

NOTE: This $\bar{\lambda}$ is valid only if the bearing is replaced at the end of the 10,000 hours of operation.

Example 2

Determine that period of operation, t, for the bearing of Example 1 that will result in the average failure rate equal to 20 failures per million hours.

Solve Eq. 1 for t

$$t = \left(\bar{\lambda} \times \alpha^{2.878}\right)^{\frac{1}{1.878}}$$

$$= \left[20 \times 10^{-6} \times (12378)^{2.878}\right]^{\frac{1}{1.878}}$$

$$= 5886 \text{ hrs.}$$

4.8 Reliability Prediction Method - Rolling Bearings Oil Lubricated

Source:

(1) International Organization for Standardization ISO 281/1-1977(E), "Rolling Bearings - Dynamic Load Ratings and Rated Life - Part 1: Calculation Methods."

(2) Marks' Standard Handbook for Mechanical Engineers, 8th ed., McGraw-Hill, 1977, pp. 8-136 through 8-142.

4.8.1 Purpose of the Method. To obtain a point estimate of the reliability in service of rolling bearings.

4.8.2 Description of the Method. Standard formulas have been developed to predict the L_{10} life of a bearing under any given set of conditions. These formulas are based on an exponential relationship of load to life which has been established from extensive testing.

$$L_{10} = \left(\frac{C}{P}\right)^{K} \times 10^{6} \text{ cyc.}$$

where

L_{10} = the number of revolutions that 90 percent (on the average) of a population of bearings will complete or exceed without failure, i.e., R = .9.

C = basic load rating, lbs.

P = equivalent radial load, lb.

K = 3 for all bearings, 10/3 for roller bearings.

To convert to hours of life (L_{10}), this formula becomes

$$L_{10} = \frac{16,666.67}{N} \left(\frac{C}{P}\right)^K \tag{2}$$

where N = rotational speed, rpm.

The basic load rating, C, value is readily obtainable from any bearing manufacturer's catalog. All bearing loads are converted to an equivalent radial load, P. Equation 3 is the general expression used for both ball and roller bearings.

$$P = XR + YT \tag{3}$$

where

R = radial load, lb.

T = thrust (axial) load, lb.

X = radial factor

Y = thrust factor.

The X-Y factors may be calculated using the methods described in Source 1 or, with some loss in precision, average values may be selected from Table 3, pp. 8-140 of Source 2.

One further formula is necessary to adjust the L_{10} life for other levels of reliability and less than optimum operating conditions.

$$L_n = a_1 \, a_2 \, a_3 \, L_{10} \tag{4}$$

where:

a_1 = life reliability factor

a_2 = material properties factor

a_3 = operating conditions factor.

The reliability factors are given in Table 4.8-1.

TABLE 4.8-1: LIFE ADJUSTMENT FACTOR OF RELIABILITY, a_1, (From Source 1)

Reliability %	L_n	a_1
90	L_{10}	1
95	L_5	0.62
96	L_4	0.53
97	L_3	0.44
98	L_2	0.33
99	L_1	0.21

The life adjustment factor for material, a_2, has not been quantified on the basis of material characteristics but rather on test results and bearing applications. In general an a_2 value of one applies. However, a value greater than one may apply to bearings made of steel of low impurity content or of special analysis. Values of a_2 should be obtained from the bearing manufacturer or from Zaretsky (1971).

Operating conditions which remain to be taken into account are the adequacy of the lubrication (at the operating speed and temperature) and conditions causing changes in material properties (i.e., high temperature causing reduced hardness). The influence on bearing life of such conditions may be considered by the application of a life adjustment factor a_3.

The calculation of basic dynamic load rating and basic rating life assumes that bearing life is limited principally by sub-surface fatigue, i.e., that the rolling elements and the ring (washer) raceways are sufficiently separated by a lubricant to make the probability of failures caused by surface distress negligible. Where this requirement if fulfilled, $a_3 = 1$, provided a lower value does not apply, for example, because of a change in material properties caused by the operating conditions.

Reduction of a_3 values should be considered whenever the viscosity of the lubricant is less than 13 mm^2/s (1 mm^2/s = 1 cST) for ball bearings or 20 mm^2/s for roller bearings at the operating temperature and/or where the rotational speed is exceptionally low (revolutions per minute times pitch dia. in mm less than 10,000). Values of a_3 greater than 1 may be considered only where the lubrication conditions are particularly favorable.

In most cases, discussions with the bearing manufacturer regarding the specifics of the application will help in quantifying a value for a_3. Carter (1972) should also be reviewed for guidance.

4.9 Reliability Prediction Method - Spur Gear Systems

Source: Savage, M., C.A. Paridon, and J.J. Coy, "Reliability Model for Planetary Gear Trains," U.S. Army Aviation Research and Development Command, AVRADCOM TR 82-C-6.

4.9.1 Purpose of the Method. To estimate the gear system life which will result in a 90 percent probability of survival.

4.9.2 Description of the Method and Example. In the design of a transmission to carry power, high strength alloy steels are normally used in key elements to help minimize the transmission's size for a given power and speed rating. As a result, the endurance limit of soft ductile steels is replaced by a higher capacity which gradually decreases with the load cycle count. Key elements, such as bearings and gears are designed on a life basis in order to keep their size reasonable.

This finite life design for lives greater than 10^7 load cycles is common practice in the design of bearings. It is the intent of this approach to extend the Weibull reliability, life and load theory to the gears as well as the bearings and to combine the component lives in a consistent fashion in order to predict the transmission reliability and life as a function of the applied load and its critical component capabilities.

Although this theory will apply just as well to a simple gear reduction or any transmission composed of bearings and gears, the presented example will be for the planetary reduction in the main rotor box of a light helicopter. A schematic diagram of a three planet reduction with the ring gear fixed and the sun gear as input is shown in Figure 4.9-1.

In this transmission the overall ratio is 5:1 and the output planetary spider or arm is to be rotated at 300 RPM. The power transmitted by the transmission is to be 200 horsepower (150 kw). The input speed of the sun gear is 1500 RPM. The gears are all 20° full depth AGMA toothed gears with a diametrical pitch of 6 in^{-1} (Ng/Dg) (a module of 4.23 mm). They are all made of case hardened A151 9310 vacuum arc remelt steel with a material constant of 21,000 psi (144 MPa). The sun gear has 24 teeth and a 4 inch pitch diameter (102 mm). The planet gears have 36 teeth each and a 6 inch (153 mm) pitch diameter. And the ring gear which is internal has 96 teeth and a pitch diameter of 16 inches (466 mm). All the gears have a 0.725 inch face width (18.4 mm).

The planet bearings are the other key elements in the transmission. These bearings are 75-02 single row cylindrical roller bearings with a 1 inch width (25 mm) and an outside diameter of 5 1/8 inches (130 mm). These bearings have a nominal basic dynamic capacity of 18,200 pounds (81 kn) each.

Since the transmission is isolated from external side and thrust loads by outside bearings, these three bearings and five gears comprise the critical elements in the transmission. It is assumed that their loading is sufficiently light to prevent early tooth rupture or bearing brinelling. It is assumed that the life of each component is based on Hertzian stress pitting fatigue and that the strength in this mode is continually reduced with load cycles.

In order to combine the reliabilities of the transmission components into a consistent system reliability, all component load cycles will be reflected

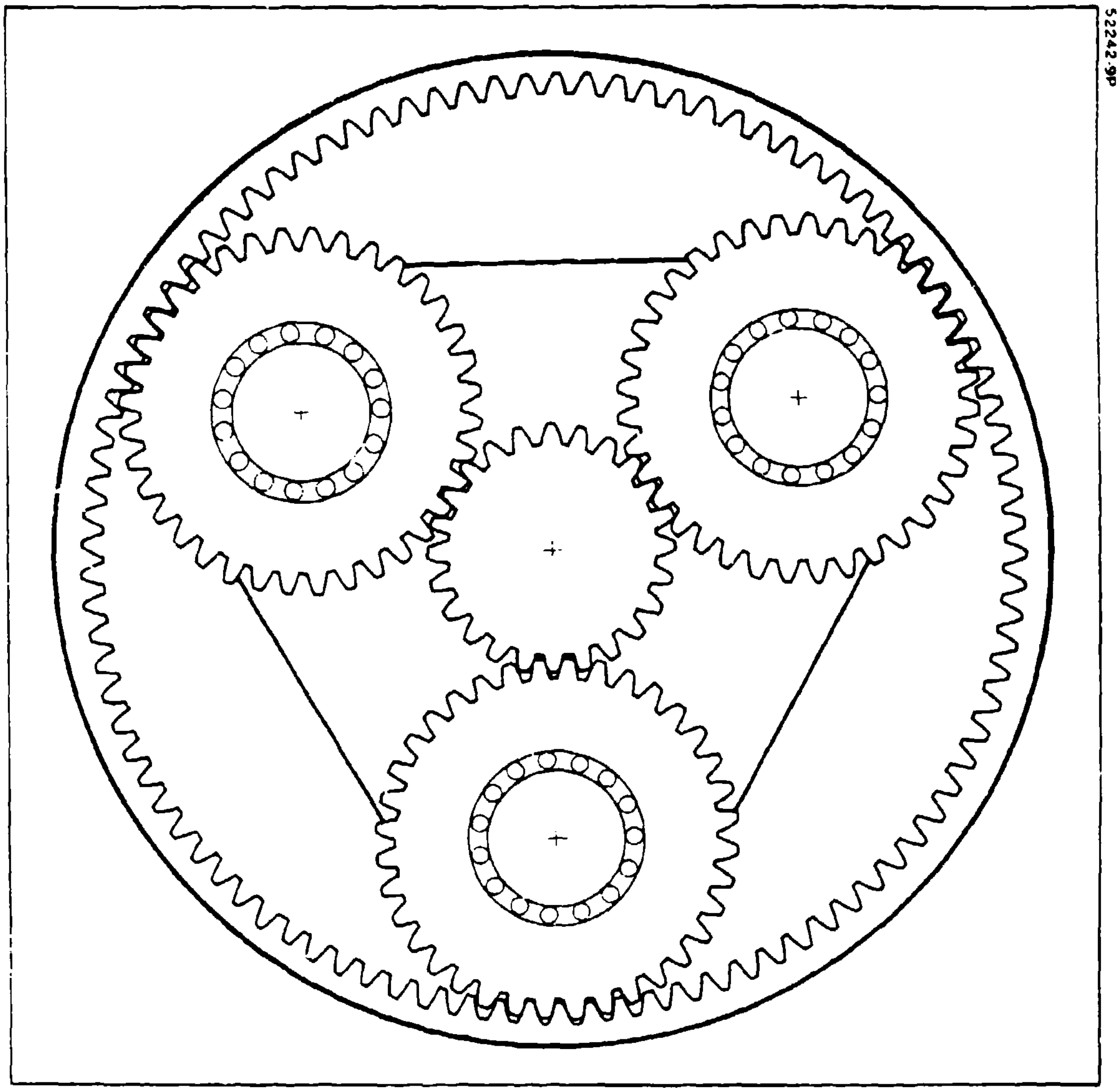

Figure 4.9-1. Planetary Gear Reduction

into a common counting basis of input sun rotations. This requires a little kinematics.

For a planetary gear train, the number of relative rotations of the plant gear with respect to the planet spider or arm in terms of input sun rotations is:

$$\Theta_{P/A} = \frac{R_S\ R_R}{R_P(R_S + R_R)}\ \Theta_S$$

where the subscripts denote the respective gears: S - sun, R - ring and P - planet. The R's represent the respective gear radii. Thus:

$$\Theta_{P/A} = \frac{-2(8)}{3(2+8)}\ \Theta_S = -0.533\ \Theta_S$$

The negative sign indicates rotation in the opposite direction to Θ_S. Since the speeds are proportional to the number of revolutions

$$\omega_{P/A} = -0.533\ (1500) = -800 \text{ RPM.}$$

Since the loads on the gears and bearings are stationary with respect to the planetary spider or arm, we are also interested in the number of relative rotations of the sun gear and the ring gear with respect to the arm in terms of input sun rotations:

$$\Theta_{S/A} = \frac{R_R}{R_S + R_R}\ \Theta_S = \left(\frac{8}{2+8}\right)\ \Theta_S$$

$$\Theta_{S/A} = 0.8\ \Theta_S$$

$$\omega_{S/A} = 0.8\ (1500) = 1200 \text{ RPM}$$

and

$$\Theta_{R/A} = -\frac{R_S}{R_S + R_R}\ \Theta_S = \frac{-2}{2+8}\ \Theta_S$$

$$\Theta_{R/A} = -0.2\ \Theta_S$$

$$\omega_{R/A} = -0.2\ (1500) = -300 \text{ RPM}$$

The forces on the components can be found from the power and input speed.

$$T_i = \frac{\text{Power}}{\omega_S}\left[63025\ \frac{\text{lb-in RPM}}{\text{HP}}\right]$$

$$T_i = \frac{200}{1500}\ (63025) = 8403 \text{ lb-in}$$

where T_i is the total input torque on the sun gear.

As shown in Figure 4.9-2, this torque produces equal tangential tooth loads F_T and a planet bearing load of twice this value,

$$F_T = \frac{T_i}{nR_S} = \frac{8403}{3(2)}$$

$$F_T = 1400.5 \text{ lbs}$$

$$F_B = 2F_2 = 2801 \text{ lbs}$$

This assumes equal load sharing among the planets and no dynamic loading in the gear meshes.

Given these loads, one can determine the ℓ_{10} lines and effective dynamic capacities of the five components in terms of their own load cycle counts. The two basic relationships for each element are:

$$\ln \frac{1}{S} = \left[\ln \frac{1}{.9}\right] \left(\frac{\ell}{\ell_{10}}\right)^E$$

where S is the reliability of the component for ℓ load cycles and ℓ_{10} is the number of cycles at this load for which the component has a reliability of 90 percent and E is the Weibull shape parameter for this reliability distribution. Normally E is taken as 1.2 for roller bearings (it may be as high as 1.5 for tapered roller bearings) and as 2.5 for gears based on testing at NASA Lewis Research Center. The second relationship is that for basic dynamic capacity, or:

$$\ell_{10} = \left(\frac{C}{F}\right)^p$$

where C is the basic dynamic capacity of the component, or the load at which 90 percent of the units will last for 10^6 load cycles. Here F is the applied load, ℓ_{10} is the corresponding 90% reliability life and p is the load life factor. The exponent p is normally taken as 10/3 for roller bearings and the NASA Lewis Research Center tests for gears indicates that 4.3 is an appropriate value for gears. The dynamic capacity equation is often modified for bearings as

$$\ell_{10} = a \left(\frac{C}{VF}\right)^p$$

where a is a factor used to increase the life estimate for improved material properties due to a reduction in impurities of the roller and race materials. According to the Roller Elements Committee of the lubrication committee of the ASME, life improvements of from 3 to 8 times are not uncommon. This factor

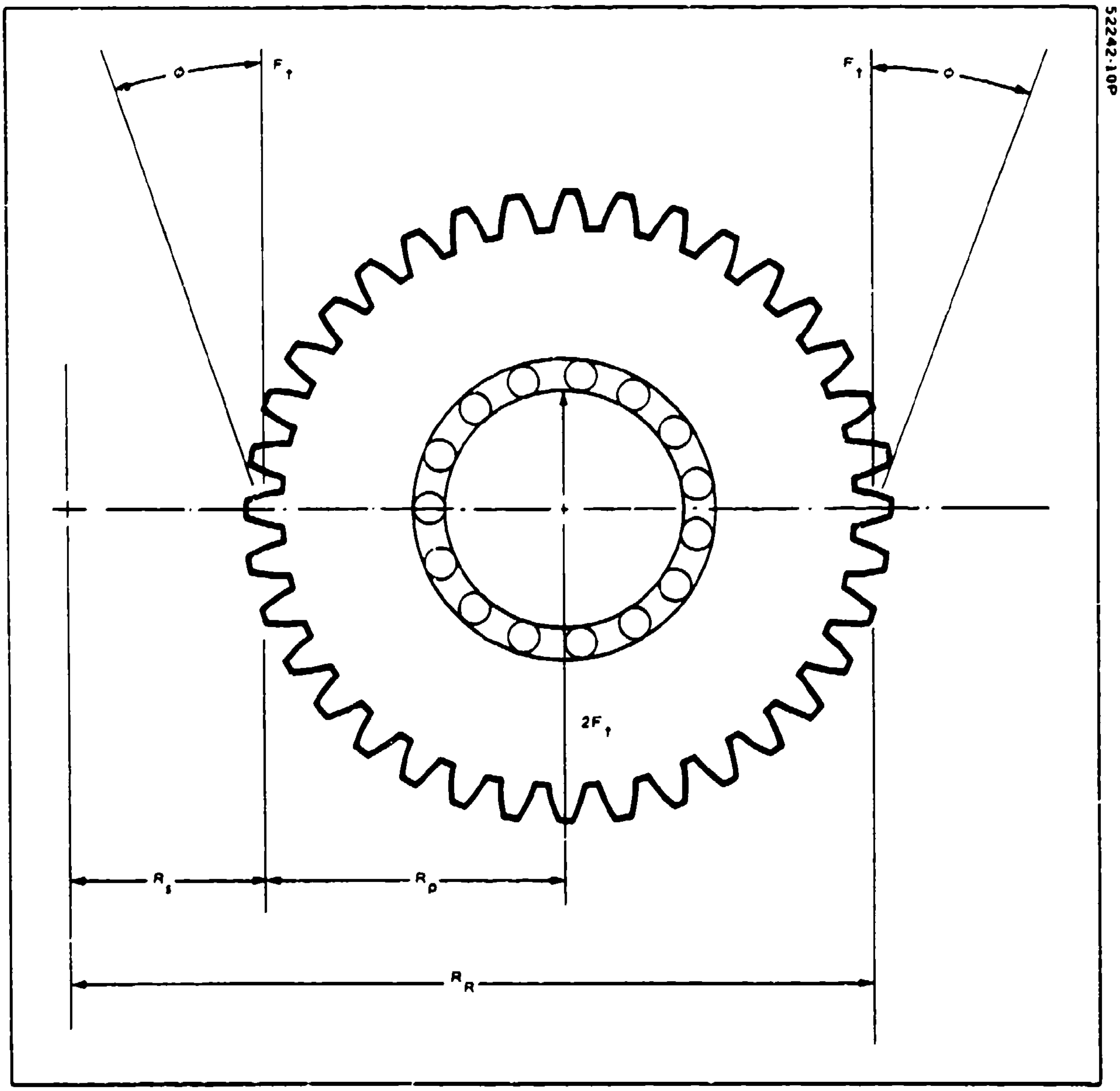

Figure 4.9-2. Planet Gear Forces

'a' may also be used to derate the life of the bearing if its speed of operation is extremely high (DN > 400,000 RPM-mm) or extremely low (DN < 10,000 RPM-mm) or if the lubrication to the bearing is inadequate. For this application the roller speed is

$$DN \approx \left[\frac{75\ \text{mmID} + 130\ \text{mmOD}}{2}\right] 800\ \text{RPM}$$

$$DN \approx 82{,}000\ \text{RPM} \cdot \text{mm}$$

as the operating speed should not be a problem. Although helicopter manufacturers use improved steels and lubrication in their transmissions and often use life improvement factors in the order of 8 in their calculations, we chose, in this example, to use a factor of 1/1.5 or 0.67 to indicate unsureness of the dynamic loading on the bearing (this is equivalent to a load factor of 1.13). At best, one can say that this factor is conservative, the 1972 AFBMA standard recommends a factor of 3 for a reasonable application, but disclaimers are also present. In addition to the life adjustment factor, there is also a load adjustment factor, V. The value of 1.2 is used since the counterformal contact on the inner race produces higher stresses than the conformed contact on the outer race does. The choice of not using this factor may be justified in the wide range of the life improvement factor. However for two identical bearings for which one has the load cycling on the inner race and the second has the same load cycling on the outer race, the first bearing will fail first due to its higher stress state.

With all this under advisement, the component ℓ_{B10} life in bearing load cycles of a single planet bearing is:

$$\ell_{B10} = a\left(\frac{C}{VF}\right)^{p}$$

$$\ell_{B10} = \frac{1}{1.5}\left[\frac{18{,}200}{1.2(2801)}\right]^{3.33}$$

$$\ell_{B10} = 184.8 \times 10^{6}\ \text{cycles}$$

In a similar fashion, the dynamic capacity of a gear tooth is related to its life as:

$$\ell_{10} = \left(\frac{C_T}{F}\right)^{p}$$

where C_T is the dynamic capacity of a tooth and F is the tangential pitch point load on that tooth. From tests on a particular gear material (AISI 9310

Vacuum Arc Remelt Steel) at over 9,000 ft/min pitch line velocity, the dynamic capacity, C_T, is given by:

$$C_T = B_1 \frac{F \sin \phi}{(\frac{1}{R_1} + \frac{1}{R_2})}$$

where B_1 is the material constant determined by test to be 21,000 psi, F is the face width of the gear, ϕ is the pitch line pressure angle and R_1 and R_2 are the pitch radii of the two gears.

For the sun-planet mesh,

$$C_S = \frac{(21{,}000)\ (.725)\ \sin\ (20°)}{\frac{1}{2.0} + \frac{1}{3.0}}$$

$$C_S = 6{,}250 \text{ lbs}$$

For the ring-planet mesh,

$$C_R = \frac{(21{,}000)\ (.725)\ \sin\ (20°)}{\frac{1}{3} - \frac{1}{8.0}}$$

$$C_R = 25{,}000 \text{ lbs.}$$

Unfortunately, the wide range of data available for bearing lives is not matched for gears. Since it is on the basis of this data that the life adjustment factors are established, corresponding factors do not exist in gearing. More statistical gear life data is really needed for gearing. The direct application of the NASA Lewis Research Center gear test data outside the load cycle range of the tests (1.2-3 X 10^7 cycles) appears to be conservative.

For a sun gear tooth and one side of a planet gear tooth

$$\ell_{S10} = \left(\frac{6250}{1400.5}\right)^{4.3} 10^6 = 620 \text{ X } 10^6 \text{ load cycles.}$$

For a ring gear tooth and the other side of the planet gear tooth

$$\ell_{R10} = \left(\frac{25000}{1400.5}\right)^{4.3} 10^6 = 241 \text{ X } 10^9 \text{ load cycles.}$$

The next step is to reflect these lines and capacities to a common counting basis, input sun torque and rotation.

For a single bearing

$$\frac{L_{B10}}{\theta_S} = \frac{\ell_{B10}}{\theta_{P/A}}$$

$$L_{B10} = \frac{\Theta_S}{\Theta_{P/A}} \ell_{B10} = \frac{1}{.533} (184.8 \times 10^6)$$

$$L_{B10} = 347 \times 10^6 \text{ Revolutions}$$

$$L_{B10} = 347 \times 10^6 \left[\frac{1}{1500 \times 60}\right] = 3856 \text{ hours}$$

and its dynamic capacity as an input torque is the torque for which this bearing life equals 10^6 sun rotations

$$D_B = \left[\frac{R_P(R_S + R_R)}{R_S R_R}\right]^{1/p} \left(\frac{nR_S C_B}{2}\right)$$

where

$$C_B = \left(\frac{C}{V}\right) a^{1/p}$$

is the modified bearing dynamic capacity

$$C_B = \left(\frac{18200}{1.2}\right) \left(\frac{1}{1.5}\right)^{1/3.33} = 13{,}430 \text{ lbs}$$

and

$$D_B = \left[\frac{3(10)}{2(8)}\right]^{1/3.33} \left(\frac{3(2)(13430)}{2}\right)$$

$$D_B = 48{,}601 \text{ lb-in.}$$

For the sun gear we must combine the lives of the individual teeth. This is done by the product of probabilities of independent events:

$S_S = S_T^{N_S}$, where S_S and S_T are the reliabilities of the sun gear and a single sun gear tooth, respectively.

Thus, $\ln \left(\frac{1}{S_S}\right) = N_S \ln \left(\frac{1}{S_T}\right)$

and

$$\ln \left(\frac{1}{S_S}\right) = N_S \left[\ln \left(\frac{1}{.9}\right)\right] \left(\frac{\ell_S}{\ell_{S10}}\right)^{e_G}$$

where ℓ_S is the life of the individual tooth in terms of its own load cycles, and e_G is the Weibull shape parameter. In terms of rotations, counting contacts with each of n planets per revolutions, this becomes:

$$\ell_S = \frac{n\Theta_{S/A}}{\Theta_S} L_S$$

or

$$\ell_S = 3(0.8)\ L_S = 2.4\ L_S$$

so each tooth receives 2.4 load cycles for each sun rotation. In terms of L_{10} lives

$$\ln\frac{1}{S_S} = \left[\ln\frac{1}{.9}\right]\left(\frac{L_S}{L_{S10}}\right)^{e_G} = N_S\left[\ln\ \frac{1}{.9}\right]\left(\frac{2.4\ L_S}{\ell_{S10}}\right)^{e_G}$$

or

$$L_{S10} = \left(\frac{1}{N_S}\right)^{1/e_G}\ \frac{\ell_{S10}}{2.4} = \left(\frac{1}{24}\right)^{1/2.5}\ \frac{620\ \text{X}\ 10^6}{2.4}$$

$$L_{S10} = 72.5\ \text{X}\ 10^6\ \text{Sun Rotations}$$

or

$$L_{S10} = 72.5\ \text{X}\ 10^6\left[\frac{1}{1500\ \text{X}\ 60}\right]\ \text{hours}$$

$$L_{S10} = 806\ \text{hours.}$$

Its dynamic capacity can be found from the tooth capacity in a similar fashion:

$$D_S = \left(\frac{1}{N_S}\right)^{1/e_G p_G}\left[\frac{R_R + R_S}{nR_R}\right]^{1/p_G}\quad (nR_S C_S)$$

$$D_S = \left(\frac{1}{24}\right)^{1/2.5(4.3)}\left[\frac{10}{3(8)}\right]^{1/4.3}\quad (3\cdot 2\cdot 6250)$$

$$D_S = 22{,}762\ \text{lb-in.}$$

For the ring gear, the calculations are similar to those for the sun gear. The reliability of the gear in terms of its teeth reliabilities are:

$$S_R = S_T^{N_R}$$

so

$$\ln\left(\frac{1}{S_R}\right) = N_R \ln\left(\frac{1}{S_T}\right)$$

and

$$\ln\left(\frac{1}{S_R}\right) = N_S \left[\ln\left(\frac{1}{.9}\right)\right] \left(\frac{\ell_R}{\ell_{R10}}\right)^{e_G}$$

where ℓ_R is the life of the individual tooth in terms of its own load cycles. In terms of sun rotations, counting contacts with each of n planets per revolution, this becomes:

$$\ell_R = n \frac{\theta_{R/A}}{\theta_S} L_R$$

or

$$\ell_R = 3(0.2)\ L_R = 0.6\ L_R$$

so each tooth receives 0.6 load cycles for each sun rotation. In terms of L_{10} lives:

$$\ln\left(\frac{1}{S_R}\right) = \left[\ln \frac{1}{.9}\right] \left(\frac{L_R}{L_{R10}}\right)^{e_G} = N_R \ln\left(\frac{1}{.9}\right)\left(\frac{.6L_R}{\ell_{R10}}\right)^{e_G}$$

or

$$L_{R10} = \left(\frac{1}{N_R}\right)^{1/e_G} \frac{\ell_{R10}}{0.6} = \left(\frac{1}{96}\right)^{1/2.5} \left(\frac{241 \times 10^9}{.6}\right)$$

$$L_{R10} = 64{,}710 \times 10^6 \text{ Sun Rotations}$$

or

$$L_{R10} = 64{,}710 \times 10^6 \left[\frac{1}{1500 \times 60}\right] \text{hours} = 719{,}000 \text{ hours.}$$

Its dynamic capacity can be found from the tooth capacity in a similar fashion.

$$D_R = \left(\frac{1}{N_R}\right)^{1/e_G p_G} \left[\frac{R_R + R_S}{nR_S}\right]^{1/p_G} (nR_S C_R)$$

$$D_R = \left(\frac{1}{96}\right)^{1/2.5(4.3)} \left[\frac{10}{3(2)}\right]^{1/4.3} (3(2)(25,000))$$

$$D_R = 110,500 \text{ lb-in.}$$

For the planet gears, the fact that each tooth is loaded on one side by the sun gear and on the other by the ring gear changes the calculation slightly.

The numbers of load cycles that each tooth sees from either sun gear or planet gear is the number of relative rotations of the planet with respect to the arm. In terms of sun gear rotations, this is

$$\frac{\ell_P}{\Theta_{P/A}} = \frac{L_P}{\Theta_S}$$

$$\ell_P = \frac{\Theta_{P/A}}{\Theta_S} L_P = 0.533 \; L_P$$

The reliability of a planet gear is the product of the reliabilities of its individual tooth faces:

$$S_P = S_{PS}{}^{Np} \cdot S_{PR}{}^{Np}$$

where S_{PS} is the reliability of a planet tooth face meshing with the sun and S_{PR} is the reliability of a planet tooth face meshing with the ring. Thus:

$$\ln\left(\frac{1}{S_p}\right) = N_p \ln\left(\frac{1}{S_{PS}}\right) + N_p \ln\left(\frac{1}{S_{PR}}\right)$$

or

$$\left(\frac{L_P}{L_{P10}}\right)^{e_G} = N_p \left(\frac{.533 \; L_P}{\ell_{S10}}\right)^{e_G} + N_p \left(\frac{.533 L_P}{\ell_{R10}}\right)^{e_G} .$$

The single tooth face lives ℓ_{S10} and ℓ_{R10} are the same as those of the mating teeth on the sun and ring gears. So:

$$L_{P10} = \left(\frac{1}{N_p}\right)^{1/e_G} \left(\frac{\ell_{S10}\ell_{R10}}{.533}\right) \left[\frac{1}{\ell_{R10}{}^{e_G} + \ell_{S10}{}^{e_G}}\right]^{1/e_G}$$

$$L_{P10} = \left(\frac{1}{36}\right)^{1/2.5} \left[\frac{(620 \times 10^6)(241 \times 10^9)}{.533}\right] \times$$

$$\left[\frac{1}{(620 \times 10^6)^{2.5} + (241 \times 10^9)^{2.5}}\right]^{1/2.5}$$

$$L_{P10} = 277 \times 10^6 \text{ Sun Revolutions}$$

$$L_{P10} = 277 \times 10^6 \left[\frac{1}{1500(60)}\right] = 3078 \text{ hours}$$

The basic dynamic capacity for a single planet gear is the input torque for which its life equals 10^6 sun rotations:

$$D_P = \left(\frac{1}{N_P}\right)^{1/e_G p_G} \left[\frac{R_P(R_S+R_R)}{R_S R_R}\right]^{1/p_G} \left(\frac{n\ R_S C_S C_R}{(C_S{}^{e_G p_G} + C_R{}^{e_G p_G})^{1/e_G p_G}}\right)$$

$$D_P = \left[\frac{1}{36}\right]^{\frac{1}{2.5(4.3)}} \left[\frac{3(10)}{2(8)}\right]^{\frac{1}{4.3}}$$

$$\times \frac{3(2)\quad(6250)\quad(25{,}000)}{[(6250)^{2.5(4.3)} + (25{,}000)^{2.5(4.3)}]^{1/(2.5)4.3}}$$

$$D_P = 31{,}100 \text{ lb-in.}$$

At this point all the components are rated for 90% reliability life and basic dynamic capacity in terms of sun rotations.

Component	Life		Dynamic Capacity
	10^6 Sun Rotations	hrs	lb-in
Plant Bearing	347	3,856	48,661
Sun	72.5	806	22,762
Ring	64,710	719,000	110,500
Planet Gear	277	3,078	31,100

The combination of these lives and capacities involves the product of the probabilities of survival of all the components

$$S_T = S_B{}^n S_S S_P{}^n S_R$$

or

$$\ln\left(\frac{1}{S_T}\right) = \ln\left(\frac{1}{.9}\right) \left\{ n\left(\frac{L_T}{L_{B10}}\right)^{e_B} + \left(\frac{L_T}{L_{S10}}\right)^{e_G} \right.$$

$$\left. + \; n\left(\frac{L_T}{L_{P10}}\right)^{e_G} + \left(\frac{L_T}{L_{R10}}\right)^{e_G} \right\} .$$

Since e_G does not equal e_B, this relation cannot be directly set to:

$$\ln\left(\frac{1}{S_T}\right) = \ln\left(\frac{1}{.9}\right) \left(\frac{L_T}{L_{T10}}\right)^{e_T} .$$

However, for values of S_T from 0.5 to 0.95, a least squares fit can be made on Weibull paper to find the values of e_T and L_{T10} which best characterize the system.

For the data of this example:

$$L_{T10} = 58.1 \times 10^6 \text{ Sun Revolutions}$$

$$L_{T10} = 58.1 \times 10^6 \left[\frac{1}{1500(60)}\right] = 646 \text{ hours}$$

and the Weibull slope for the system is

$$e_T = 2.12.$$

At similar situation exists for the system's dynamic capacity. To find:

$$C_{T10} = \left(\frac{D_T}{T_1}\right)^{P_T}$$

one can take the equation for L_{T10} and vary the input torque over a range of 0.1 D_T to D_T and find the corresponding L_{T10} lives. A least square fit of this L_{T10} vs. T_1 data on log-log paper will produce a linear curve for which

$$D_T = 22{,}605 \text{ lb-in}$$

and

$$e_T = 4.03.$$

So a system Weibull and load life model for this example is

$$\ln\left(\frac{1}{S_T}\right) = \ln\left(\frac{1}{.9}\right)\left[\frac{L_T}{58.1}\right]^{2.12}$$

and

$$L_{T10} = \left(\frac{22,605}{T_i}\right)^{4.03}$$

4.10 Reliability Prediction Method - Minimum Information

The methods of this section are to be employed when there is not sufficient statistical data nor sufficient structural/analytical information concerning the nonelectronic part to allow the use of the other methods of this notebook to obtain reliability predictions.

The circumstances which lead to the necessity of using this section are partly due to rapid advancement of technology. New parts are constantly being introduced with hardly enough lifetime history to allow the vendor to set a warranty or service life (also called useful life). This service life is usually available from the vendor and can be used in conjunction with data from similar devices to provide reliability predictions.

The following examples illustrate the use of this type of information in determining Weibull parameters and failure rates. In the Weibull case, two quantities (usually the shape parameter or "slope" as it is often called, and the vendor supplied service life) are used. In the constant failure rate case (exponential distribution), the service life is sufficient.

4.10.1 Examples

Example 1. The expected service life of a hydraulic motor has been calculated by the vendor to be 12,413 hours where the service life is defined as the minimum life expected without failure of the motor section exclusive of the bearing section. The bearing section has been calculated to have an L_{10} life of 50,000 hours in this application, i.e., 90% probability of surviving 50,000 hours. The preceding constitutes the only information available to be reliability analyst.

In the following calculation, the motor section service life estimate will be conservatively assumed to be the tenth pecentile of failure, L_{10}, of a Weibull distribution. The slope, β_M, is assumed to be 2, which is consistent with the scatter in lives to be expected when fatigue is the dominant failure mechanism. The calculated bearing section L_{10} is reduced to 25,000 hours to account for less than ideal lubrication. The distribution is assumed to be Weibull with a slope, β_B, of 1.5 which is consistent with practice.

The characteristic lives of the motor section, α_M can now be computed. Since the L_{10} life of the motor is 12,413, it must be that

$$.90 = \exp \left\{ -(L_{10}/\alpha_M)^{\beta_M} \right\}$$

or

$$.90 = \exp \left\{ - (12413/\alpha_M)^2 \right\}$$

so that $\alpha_M = (12,413)/(-\ln(.90))^{1/2} = 38,241$ hours

Similarly, $\alpha_B = (25,000)/(-\ln(.90)^{1/1.5}) = 112,070$ hours

Finally, an average failure rate for a use life, t, is calculated using an average Weibull competing risk cumulative hazard model:

$$\bar{\lambda}_t = \left(\frac{t^{\beta_m - 1}}{\alpha_m^{\beta_m}} + \frac{t^{\beta_B - 1}}{\alpha_B^{\beta_B}} \right)$$

where:

t = 10,000 hours $\beta_m = 2$
α_M = 38,241 $\beta_B = 1.5$.
α_B = 112,070

$$\bar{\lambda}_{10,000} = \left[\frac{10,000}{(38241)^2} + \frac{(10,000)^{.5}}{(112070)^{1.5}} \right] = 9.5 \times 10^{-6}$$

or 9.5 failures per million hours.

Should this failure rate be unacceptably high, a lower failure rate can be obtained by reducing the in-use life or by redesign of the motor section to obtain a greater L_{10} life rating.

Example 2. <u>Ball Screw Reliability Estimation</u>

A ball screw is to be applied in an environment which includes vibration and salt-laden air. Vendor catalog information provides an L_{10} life of 20 x 10^6 inches under the conditions of loading and lubrication of this application. Discussions with the vendor's engineering staff suggest that the given L_{10} is realistic provided a life correction factor of 0.5 is used to account for the special environmental conditions. The vendor also states that test data indicates that the lives will follow the Weibull distribution with a β of 3 when grease lubricated as in this application. In operation there will be 60 inches of travel per cycle and 13 cycles per hour.

Estimate the reliability for a service life of 10,000 hours.

Life $L_{10} = 20 \times 10^6 \times 0.5$ inches $= 10^7$ inches.

cyc/hr = 13
in/cyc = 60

$$\text{Weibull Distribution} = 1 - e^{-\left(\frac{t}{\alpha}\right)^{\beta}} \qquad \beta = 3$$

Service Life (t) = 10,000 hours.

Convert L_{10} inches to L_{10} hours.

$$L_{10}\text{ hrs} = \frac{10^7}{(13)\ (60)} = 12{,}821\text{ hours.}$$

Since $\beta = 3$, and since the L_{10} life satisfies $.90 = \exp\left\{-(L_{10}/\alpha)^{\beta}\right\}$, it follows that $\alpha = (12821)/(-\ln(.9))^{1/3} = 27{,}145$ hours. Thus, the reliability for t = 10,000 hours is R (10,000) = $\exp\left\{-(10000/27145)^3\right\} = 0.951$.

If an average failure rate over the 10,000 hours service life is required, it can be calculated as follows:

$$\bar{\lambda}(t) = \frac{t^{\beta-1}}{\alpha^{\beta}}$$

$$\bar{\lambda}(10{,}000) = \frac{(10{,}000)^2}{(27145)^3} = 5.0 \times 10^{-6}$$

or 5 failures per million hours.

Example 3. <u>Estimation of a Constant Failure Rate Based on Service Life</u>.

As demonstrated in this Notebook, most of the time it can be assumed that the nonelectronic parts represented in this Notebook have constant failure rates. In this case, if the only information available is a vendor supplied "warranty" or "service" life, then a failure rate is easily estimated.

Occasionally, the vendor will indicate at which percentile the warranty is developed. That is, if a warranty or service life of 1000 hours is specified, the vendor may have done life testing which indicates that 1000 hours is the life beyond which 90% of the devices will survive on the

average. This would make 1000 hours the 10th percentile of the life distribution. To compute the constant failure rate, simply set $0.90=\exp(-\lambda\ 1000)$ and solve for λ. In this case, $\lambda = -\ln(0.90)/1000 = 0.000105$ or 105 failures per million hours. In general, use the following formula:

$$\text{failure rate} = -\ln(1-p)/(\text{warranty time})$$

where p is the quantile associated with the warranty time. Usually, $p=0.10$ but occasionally, if the vendor information is suspect, or the vendor will not say what value p should be, use $p=0.05$.

5.0 PART FAILURE CHARACTERISTICS

5.1 Introduction. The following sections of the notebook describe the analyses of the nonelectronic part failure data collected for this study. Section 5.2 presents the results of fitting the exponential distribution to the failure data for each part class, part type, and environment. Sections 5.3 - 5.5 present the results of testing the fit of the exponential distribution against Weibull alternatives for the data corresponding to some items. Section 5.6 gives part malfunction data and frequency of occurrence for some parts. It should be pointed out that the data used for preparation of this notebook was screened to exclude secondary failures and failures caused by maintenance personnel.

The environment abbreviations in the tables of this section follow the conventions of MIL-HDBK-217D. For convenience, these abbreviations are defined in table 5.1.1. More detailed descriptions may be found in MIL-HDBK-217D.

Finally, an explanation of the confidence intervals presented in sections 5.2 through 5.5 is necessary. These confidence intervals (for failure rate in the exponential cases, and for the shape and scale parameters in the Weibull analyses) have been called "60% confidence intervals." In the tables, however, the lower and upper bounds are labeled "80% lower" and "80% upper" bounds. This has been done so that either one-sided bound can be used by itself to form a one-sided 80% confidence interval if desired. When the two 80% bounds are combined to form a two-sided interval, the resultant confidence is 60%.

TABLE 5.1.1 DEFINITIONS OF ENVIRONMENT ABBREVIATIONS

Abbreviation	Environment
AIF	Airborne, Inhabited, Fighter
AIT	Airborne, Inhabited, Transport
ARW	Airborne, Rotary Winged
AUF	Airborne, Uninhabited, Fighter
AUT	Airborne, Uninhabited, Transport
GB	Ground, Benign
GF	Ground, Fixed
GM	Ground, Mobile
ML	Missile, Launch
NS	Naval, Sheltered
NSB	Naval, Submarine
NU	Naval, Unsheltered

5.1.1 Use of Constant Failure Rate Analyses. We recommend that the results presented in Section 5.2 be used as follows. First, find the

part class, part type, and environment of interest in the tables listed in section 5.2. The corresponding table will give a point estimate (also referred as a "prediction" in many reliability circles) of failure rate per million hours. A two-sided 60% confidence bound on the failure rate is also given in order to give the user a feel for the precision of the estimate. Also included is the number of independent sources (usually projects) which contributed to the estimates, along with total number of failures, total part operating hours and an estimate of mean life (i.e., mean operating time to failure). In a large number of cases, less than 50,000 hours of operating time were available so that care should be taken to examine the width of these confidence intervals. In cases where the total part operating hours shown are less than 1,000 hours, failure rate information is not tabulated. For these cases, the user should be very cautious in using the information presented for reliability purposes. Wherever there is more than one source contributing to an estimate, the observed significance level of a statistical test of homogeneity (also called a p-value, see Cox & Hinkley (1974), p. 66, for further discussion) is given. This test of homogeneity was performed in order to determine if the sources reporting failures were statistically different. In general, the observed significance level is between 0 and 1 with values close to 0 indicating evidence to reject homogeneity. We recommend a threshold of 0.05 for the homogeneity test, i.e., homogeneity is rejected if the observed significance level is below 0.05.

5.1.2 Use of Weibull Analyses. Most data collected was restricted to total operating time and total number of failures. While this approach is adequate (sufficient, in fact, in the statistical sense) when dealing with the exponential distribution, it does not provide a means of evaluating the "fit" or validity of the exponential model. The validity of the exponential distribution for describing the life distribution for nonelectronic parts was one of the central issues addressed by this study.

In order to address this important issue, data sets that contained actual part lifetimes for each failed part and total operating time were collected. In most cases, part lifetime data simply did not exist. However, for a significant number of part classes, part types, and environments, these data were available and were used to test the fit of the exponential distribution against Weibull alternatives. The Weibull family of distributions is rich enough to approximate virtually any unimodal life distribution and is therefore applicable for most nonelectronic parts. Moreover, the Weibull distribution is the resultant extreme-type distribution for describing lifetimes of nonelectronic parts which fail in accordance with a "weakest link" scenario. This technique for testing the fit of a distribution by embedding it in a parametric family of distributions is called a "smooth goodness-of-fit test," and is described in further detail in Lawless (1982), p. 438. Since the lifetime data was not collected under any of the commonly treated sampling plans, i.e., nonreplacement type I or II censoring, or complete samples, the goodness-of-fit procedure had to be developed ad hoc, and the smooth goodness-of-fit approach allowed the use of standard

likelihood ratio procedures in performing the test. The results of these analyses are presented in sections 5.3 - 5.5.

If the same part class, part type, and environment is reported in sections 5.3 - 5.5 a Weibull analysis was performed (this is indicated in the index to Section 5.2). Use the information in the Weibull table to decide whether to adopt the Weibull distribution, or retain the exponential distribution. For each of the part classes, part types and environments analyzed in sections 5.3 - 5.5, a table summarizing the results is presented. Each table contains a point estimate of mean life (i.e. mean time to failure in hours), and point and 60% confidence interval estimates for the Weibull scale parameter (in hours) and shape parameter (unitless). Also included are total part operating hours, and total failures. In cases where there was a predominant failure mode, this failure mode is given in the comments field, along with the observed significance level for the test of exponentiality. The observed significance level for testing exponentiality is used to decide whether to adopt the Weibull model, or to retain the exponential model. As before, we recommend that the threshold value be 0.05, i.e. reject exponentiality if the observed significance level is less than 0.05, and retain exponentiality otherwise. However, depending on the particular circumstances, the analyst using the observed significance level may wish to base the decision on a different threshold value, e.g. 0.10, 0.005, 0.001, etc. In the majority of cases, the exponential model is shown to be the best fit based on the 0.05 level of significance.

If the Weibull model is shown to be the better fitting model, it may still be desirable to approximate the distribution by the exponential distribution. This approximation is useful if the nonelectronic part(s) under consideration are part of a large system in which the other elements exhibit exponentially distributed lifetimes, and it is necessary to analyze the system as a whole. For exponential approximations it is recommended that the point estimate of the mean for the Weibull be used in the exponential model whenever the Weibull shape parameter is greater than one. When the Weibull shape parameter is less than one, use the mean life estimate from the appropriate table in section 5.2. These guidelines will yield conservative results (i.e. lower bounds) when computing system reliability for the series string in the case where the Weibull shape parameter is greater than one.

A total of 145 part classes/ types were analyzed in sections 5.3 - 5.5. In 6 of those cases exponentiality would be rejected at the 0.05 level of significance. This is not statistically significant. These results suggest that the exponential distribution is an adequate life model for most nonelectronic parts that are operated for time periods smaller than those analyzed in sections 5.3 - 5.5, i.e., there is a time period for most nonelectronic parts during which a constant failure rate model is appropriate. This phenomenon, conjectured in previous editions of this notebook, is supported by the results of sections 5.3 - 5.5.

5.2 Constant Failure Rate Analysis

5.2.1 Index to Section 5.2

Part Class	Part Type	Identification Number*
ACCELEROMETER	FORCED BALANCED	1*
ACCELEROMETER	PENDULUM, LINEAR	2
ACCELEROMETER	PENDULUM, SINGLE AXIS	3
ACCUMULATOR	HYDRAULIC	4
ACCUMULATOR	HYDRAULIC-PNEUMATIC	5
ACTUATOR	ELECTRICAL	6
ACTUATOR	ELECTROMECHANICAL (LINEAR)	7*
ACTUATOR	ELECTROMECHANICAL (ROTARY)	8
ACTUATOR	ELECTROMECHANICAL (LINEAR)	9*
ACTUATOR	HYDRAULIC-PNEUMATIC	10
ACTUATOR	MECHANICAL	11
ACTUATOR	ROTARY	12
AIR CONDITIONER	COMFORT	13
AIR CONDITIONER	GENERAL	14
AIR CONDITIONER	PROCESS	15
ANTENNA	COMMUNICATION	16*
ANTENNA	MICROWAVE (COMMUNICATION)	17
ANTENNA	RADAR	18
AXLE	GENERAL	19*
AZIMUTH ENCODER	OPTICAL	20*
BATTERY	RECHARGEABLE	21*
BEARING	BALL	22*
BEARING	ROLLER	23*
BEARING	SLEEVE	24*
BEARING NUT	GENERAL	25
BELLOWS	GENERAL	26*
BELT	GEARED	27
BELT	TIMING	28*
BELT	V-BELT	29*
BINOCULAR	NITROGEN PRESSURIZED	30
BLADE ASSEMBLY	GENERAL	31
BLOWERS & FANS	AXIAL	32*
BLOWERS & FANS	CENTRIFUGAL	33*
BOOT (DUST & MOISTURE)	GENERAL	34
BRAKE	ELECTROMECHANICAL	35*
BRUSHES	ELECTRIC MOTOR	36*
BURNER	CATALYTIC	37
BUSHINGS	GENERAL	38*
CAM	GENERAL	39
CAMERA	MOTION (TV)	40*
CESIUM BEAM TUBE	GENERAL	41
CIRCUIT PROTECTION DEVICE	SPARK GAP	42*
CIRCUIT PROTECTION		

Note: An asterisk "" indicates that a Weibull analysis is included in one or more environments in Sections 5.3 - 5.5.

Part Class	Part Type	Identification Number*
DEVICE	SURGE ARRESTER	43*
CLUTCH	FRICTION	44*
CLUTCH	GENERAL	45
COMPRESSOR	GENERAL	46
COMPRESSOR	HIGH PRESSURE	47
COMPRESSOR	LOW PRESSURE	48
COMPUTER MASS MEMORY	FIXED HEAD DISK	49*
COMPUTER MASS MEMORY	MAGNETIC TAPE	50*
COMPUTER MASS MEMORY	MOVABLE HEAD DISK	51*
CONTROL TUBE ASSEMBLY	GENERAL	52
CORD/CABLE	GENERAL	53
COUNTER	ANALOG	54
COUNTER	DIGITAL	55
COUNTER	MECHANICAL	56
COUNTER	WATER CLOCK	57
COUPLING	FLEXIBLE	58*
COUPLING	FLUID	59
COUPLING	GENERAL	60
COUPLING	RIGID	61*
CRANKSHAFT	GENERAL	62*
CROSS HEAD	GENERAL	63
DIAPHRAGMS BURST	GENERAL	64*
DIFFUSER	GENERAL	65
DISC ASSEMBLY	GENERAL	66
DISTILLATION UNIT	FROM DISTILLING PLANT	67
DRIVE	GEAR	68*
DRIVE	GENERAL	69
DRIVE	VARIABLE PITCH	70*
DRIVE FOR COMPUTER TAPES & DISCS	CAPSTAN MOTOR	71
DRIVE FOR COMPUTER TAPES & DISCS	DISCS	72*
DRIVE FOR COMPUTER TAPES & DISCS	MAGNETIC TAPE TRANSPORT	73*
DRIVE FOR COMPUTER TAPES & DISCS	REEL MOTOR	74
DRIVE ROD	GENERAL	75
DRUM	GENERAL	76*
DUCT	GENERAL	77*
ELECTRIC HEATERS	RESISTANCE	78*
ELECTROMECHANICAL TIMERS	GENERAL	79*
ENGINES	GENERAL	80
FEEDHORN	WAVEGUIDE	81
FILTER	GAS (AIR)	82*
FILTER	LIQUID	83*

Note: An asterisk "" indicates that a Weibull analysis is included in one or more environments in Sections 5.3 - 5.5.

Part Class	Part Type	Identification Number*
FILTER	OPTICAL	84
FITTINGS	GENERAL	85
FITTINGS	PERMANENT	86*
FITTINGS	QUICK DISCONNECT	87*
FITTINGS	THREADED	88*
FLASH LAMP	GENERAL	89
FUSE HOLDER	BLOCK	90*
FUSE HOLDER	EXTRACTOR POST	91
FUSE HOLDER	PLUG	92*
GAS DRYER DESICATOR	MOLECULAR SIEVE	93
GASKETS & SEALS	DYNAMIC	94*
GASKETS & SEALS	STATIC	95*
GEAR	ANTIROTATION	96
GEAR	BEVEL	97*
GEAR	HELICAL	98*
GEAR	HYPOID	99
GEAR	SPUR	100
GEAR	WORM	101
GEAR BOX	MULTIPLIER	102
GEAR BOX	REDUCTION	103
GEAR TRAIN	BEVEL	104
GENERATOR	AC	105
GENERATOR	GENERAL (OXYGEN GENERATOR)	106
GLASS (SIGHT GAUGE)	GENERAL	107
GROMMET	GENERAL	108
GIMBALS	GENERAL	109
GIMBALS	TORQUE	110
GYROSCOPE	SINGLE AXIS	111
GYROSCOPE	TWO AXIS ROTOR	112
HEAT EXCHANGERS	COPLATES	113*
HEAT EXCHANGERS	GENERAL	114
HEAT EXCHANGERS	RADIATOR	115*
HEATER	WATER	116
HEATER BLANKETS	GENERAL	117
HEATER, FLEX ELEMENT	HEATER TAPE	118
HIGH SPEED PRINTER	ELECTROSTATIC	119*
HIGH SPEED PRINTER	IMPACT	120*
HIGH SPEED PRINTER	THERMAL	121
HOSE	FLEXIBLE	122
HOSE	FLEXIBLE, PROPELLANT	123
HOSE	GENERAL	124*
HOUSING	GENERAL	125
INCINERATOR	FROM SEWAGE TREATMENT	126
INSTRUMENTS	AMMETER	127*
INSTRUMENTS	FLOW METER	128
INSTRUMENTS	HUMIDITY INDICATOR	129

Note: An asterisk "" indicates that a Weibull analysis is included in one or more environments in Sections 5.3 - 5.5.

Part Class	Part Type	Identification Number*
INSTRUMENTS	INDICATOR	130
INSTRUMENTS	INDICATOR (LIGHT)	131
INSTRUMENTS	INDICATOR (FLUID LEVEL)	132
INSTRUMENTS	PRESSURE GAUGE	133
INSTRUMENTS	TIME METER	134
INSTRUMENTS	TOTAL TIME METER	135
INSTRUMENTS	VOLTMETER	136*
JOINT, MICROWAVE ROTARY	GENERAL	137*
KEYBOARD	ELECTROMECHANICAL	138*
KEYBOARD	GENERAL	139
KEYBOARD	MECHANICAL	140
KNOB	GENERAL	141
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Note: An asterisk "" indicates that a Weibull analysis is included in one or more environments in Sections 5.3 - 5.5.

Part Class	Part Type	Identification Number*
PUMP	HYDRAULIC (ROTARY)	175
PUMP	PNEUMATIC	176*
PUMP	ROTARY	177
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SENSORS/TRANSDUCER/ TRANSMITTER	MOTION	201
SENSORS/TRANSDUCER/ TRANSMITTER	PRESSURE	202*
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Note: An asterisk "" indicates that a Weibull analysis is included in one or more environments in Sections 5.3 - 5.5.

Part Class	Part Type	Identification Number*
SPRING	GENERAL	213
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SWITCH	INTERLOCK	220
SWITCH	PRESSURE (AIR FLOW)	221*
SWITCH	ROCKER	222*
SWITCH	THERMOSTATIC	223*
SWITCH	THUMBWHEEL	224*
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TANK	PRESSURIZED	232
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TELESCOPE	GENERAL	234
TERMINAL BOARDS	GENERAL	235
THERMOCOUPLE	GENERAL	236
TRACK BALL	ELECTROMECHANICAL	237*
TRANSMISSION	GENERAL	238
TRUNNION ASSEMBLY	GENERAL	239
VALVE	CONTROL-MANUAL	240
VALVE	GAS (AIR-VENT)	241
VALVE	HYDRAULIC	242*
VALVE	PNEUMATIC	243*
VALVE	SOLENOID OPERATED	244
VALVE (ISOLATION)	PYROTECHNICALLY ACTUATED VALVE	245
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Note: An asterisk "" indicates that a Weibull analysis is included in one or more environments in Sections 5.3 - 5.5.

ACCELEROMETER / FORCED BALANCED					IDENTIFICATION NUMBER 1
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	37547.	18.562	26.633	37.887

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	2	8	300376	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.55

ACCELEROMETER / PENDULUM, LINEAR					IDENTIFICATION NUMBER 2
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	32886.	15.559	30.408	55.906

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	3	98657	

ACCELEROMETER / PENDULUM, SINGLE AXIS					IDENTIFICATION NUMBER 3
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	164889.	3.747	6.065	9.590

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	5	824445	

ACCUMULATOR / HYDRAULIC					IDENTIFICATION NUMBER 4
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	3780.	59.038	264.550	792.261

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	3780	

ACCUMULATOR / HYDRAULIC-PNEUMATIC — IDENTIFICATION NUMBER 5

ENV	DIST. TYPF	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	1914.	481.314	522.513	587.516

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	116	222004	

ACTUATOR / ELECTRICAL | IDENTIFICATION NUMBER 6

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	**********	0.0	0.000	8.225
GF	EXPONENTIAL	214907.	2.875	4.653	7.358
GM	EXPONENTIAL	6047.	128.783	165.368	212.044
NU	EXPONENTIAL	43667.	11.718	22.901	42.103

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	0	195696	
GF	2	5	1074536	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.87
GM	1	15	90707	
NU	1	3	131000	

ACTUATOR / ELECTROMECHANICAL (LINEAR) — IDENTIFICATION NUMBER 7

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	903.	1063.898	1107.625	1153.341
GB	EXPONENTIAL	*********	0.0	0.000	124.985

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	459	414400	
GB	1	0	12878	

ACTUATOR / ELECTROMECHANICAL (ROTARY) — IDENTIFICATION NUMBER 8

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GB	EXPONENTIAL	*********	0.0	0.000	249.970

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GB	1	0	6439	

ACTUATOR / ELECTROMECHANICAL (LINEAR) — IDENTIFICATION NUMBER 9

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	111194.	2.007	8.993	26.933
ML	EXPONENTIAL	*********	SEE NOTE BELOW		

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	1	111194	
ML	1	0	91	

NOTE: Low total part operating hours, develop failure data with caution

ACTUATOR / HYDRAULIC-PNEUMATIC | IDENTIFICATION NUMBER 10

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	1782.	489.140	561.274	644.497
AUT	EXPONENTIAL	27878.	18.354	35.871	65.948
GM	EXPONENTIAL	4610.	48.409	216.920	649.619

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	44	78393	
AUT	1	3	83634	
GM	1	1	4610	

ACTUATOR / MECHANICAL — IDENTIFICATION NUMBER 11

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	195696.	1.140	5.110	15.303
GM	EXPONENTIAL	29741.	13.859	33.624	71.943

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	195696	
GM	1	2	59481	

ACTUATOR / ROTARY — IDENTIFICATION NUMBER 12

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	12538.	55.588	79.758	113.480

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	8	100304	

AIR CONDITIONER / COMFORT					IDENTIFICATION NUMBER 13
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	1406.	635.451	711.111	796.307
GM	EXPONENTIAL	**********	0.0	0.000	27.060

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	64	90000	
GM	1	0	59481	

AIR CONDITIONER / GENERAL					IDENTIFICATION NUMBER 14
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	**********	0.0	0.000	847.136

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	0	1900	

AIR CONDITIONER	/ PROCESS		IDENTIFICATION NUMBER 15		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	*********	0.0	0.000	12.876

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	0	125000	

ANTENNA	/ COMMUNICATION		IDENTIFICATION NUMBER 16		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	150188.	2.744	6.658	14.246

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	2	2	300376	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.77

ANTENNA / MICROWAVE (COMMUNICATION) IDENTIFICATION NUMBER 17

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	52302.	16.088	19.120	22.734

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	29	1516770	

ANTENNA / RADAR					IDENTIFICATION NUMBER 18
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	169.	5563.172	5913.230	6287.363
GF	EXPONENTIAL	500000.	0.446	2.000	5.989
GM	EXPONENTIAL	8710.	25.625	114.812	343.830
NU	EXPONENTIAL	87118.	2.562	11.479	34.375

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	205	34868	
GF	1	1	500000	
GM	2	1	8710	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.13
NU	3	1	87120	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.56

AXLE / GENERAL					IDENTIFICATION NUMBER 19
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	104835.	3.932	9.539	20.410

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	2	2	209669	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.85

AZIMUTH ENCODER / OPTICAL — IDENTIFICATION NUMBER 20

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	4845.	174.759	208.408	243.927
NSB	EXPONENTIAL	23250.	24.695	43.011	72.276
NU	EXPONENTIAL	24510.	9.105	40.800	122.185

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	2	31	150188	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.92
NSB	1	4	93000	
NU	1	1	24510	

BATTERY / RECHARGEABLE					IDENTIFICATION NUMBER 21
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	186.	5131.805	5379.859	5641.117
GF	EXPONENTIAL	1433894.	0.454	0.697	1.055
GM	EXPONENTIAL	121420.	5.088	8.236	13.023

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	337	62641	
GF	5	6	8603396	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.90
GM	4	5	607102	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.99

BEARING / BALL			IDENTIFICATION NUMBER 22		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	3688.	242.952	271.142	302.800
AUF	EXPONENTIAL	198680.	4.545	5.033	5.577
AUT	EXPONENTIAL	330237.	1.739	3.028	5.089
GF	EXPONENTIAL	447103.	1.829	2.237	2.735
GM	EXPONENTIAL	165558.	4.546	6.040	8.002
NS	EXPONENTIAL	31552.	19.580	31.694	50.116
NU	EXPONENTIAL	58880.	9.751	16.984	28.540

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	67	247103	
AUF	2	77	15298373	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.71
AUT	1	4	1320948	
GF	3	22	9836258	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.46
GM	3	12	1986699	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.91
NS	2	5	157760	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.99
NU	3	4	235520	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.20

BEARING / ROLLER					IDENTIFICATION NUMBER 23
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	9150.	71.107	109.296	165.324
AUT	EXPONENTIAL	*********	0.0	0.000	16.450
GM	EXPONENTIAL	120150.	5.142	8.323	13.161
NU	EXPONENTIAL	147060.	1.518	6.800	20.364

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	6	54897	
AUT	1	0	97848	
GM	2	5	600752	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.99
NU	1	1	147060	

BEARING / SLEEVE			IDENTIFICATION NUMBER 24		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	2889.	278.111	346.102	430.448
AUT	EXPONENTIAL	293544.	0.760	3.407	10.202
GF	EXPONENTIAL	202415.	3.443	4.940	7.028
GM	EXPONENTIAL	214554.	3.152	4.661	6.814

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	19	54897	
AUT	1	1	293544	
GF	5	8	1619318	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.53
GM	2	7	1501880	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.86

BEARING NUT / GENERAL			IDENTIFICATION NUMBER 25		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	1830.	425.572	546.468	700.711

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	15	27449	

BELLOWS / GENERAL					IDENTIFICATION NUMBER 26
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	97848.	2.281	10.220	30.608
GM	EXPONENTIAL	75094.	5.489	13.317	28.493
NS	EXPONENTIAL	26200.	8.518	38.168	114.303

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	97848	
GM	2	2	150188	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.77
NS	1	1	26200	

BELT / GEARED			IDENTIFICATION NUMBER 27		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	*********	0.0	0.000	17.927

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	0	89785	

BELT / TIMING			IDENTIFICATION NUMBER 28		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	27846.	23.364	35.912	54.322
GM	EXPONENTIAL	100125.	5.110	9.987	18.382

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	6	167074	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.09
GM	2	3	300376	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.82

BELT / V-BELT					IDENTIFICATION NUMBER 29
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	59481.	3.752	16.812	50.348

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	59481	

BINOCULAR / NITROGEN PRESSURIZED					IDENTIFICATION NUMBER 30
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	945.	607.566	1058.201	1778.231

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	4	3780	

BLADE ASSEMBLY / GENERAL					IDENTIFICATION NUMBER 31
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS)		
			80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	2745.	294.660	364.312	450.364

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	20	54898	

BLOWERS & FANS		/ AXIAL		IDENTIFICATION NUMBER 32	
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AIT	EXPONENTIAL	8340.	108.908	119.900	132.078
ARW	EXPONENTIAL	2246.	401.425	445.148	493.943
AUT	EXPONENTIAL	2059.	437.736	485.774	539.422
GB	EXPONENTIAL	*********	0.0	0.000	4.764
GF	EXPONENTIAL	82575.	11.060	12.110	13.268
GM	EXPONENTIAL	64071.	12.542	15.608	19.411
NS	EXPONENTIAL	631267.	1.319	1.584	1.904
NSB	EXPONENTIAL	28800.	7.749	34.722	103.984
NU	EXPONENTIAL	*********	0.0	0.000	68.259

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AIT	1	86	717264	
ARW	1	75	168483	
AUT	2	74	152334	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.23
GB	1	0	337888	
GF	2	96	7927205	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.61
GM	4	19	1217343	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.28
NS	3	26	16412950	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.09
NSB	1	1	28800	
NU	1	0	23580	

BLOWERS & FANS / CENTRIFUGAL

IDENTIFICATION NUMBER 33

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	3123.	280.416	320.224	365.942
GF	EXPONENTIAL	153191.	4.662	6.528	9.081
GM	EXPONENTIAL	206618.	2.990	4.840	7.653
NS	EXPONENTIAL	120964.	6.302	8.267	10.819
NSB	EXPONENTIAL	*********	0.0	0.000	111.775

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	47	146772	
GF	4	9	1378716	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.18
GM	3	5	1033090	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.78
NS	3	13	1572530	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.14
NSB	1	0	14400	

BOOT (DUST & MOISTURE) / GENERAL			IDENTIFICATION NUMBER 34		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	3050.	234.177	327.881	456.106

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	9	27449	

BRAKE / ELECTROMECHANICAL			IDENTIFICATION NUMBER 35		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	62500.	6.595	16.000	34.234
GM	EXPONENTIAL	4765.	182.884	209.855	240.971
NU	EXPONENTIAL	9403.	61.064	106.355	178.722

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	2	125000	
GM	2	44	209669	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07
NU	2	4	37610	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.67

BRUSHES		/ ELECTRIC MOTOR			IDENTIFICATION NUMBER 36
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	*********	0.0	0.000	32.899
GF	EXPONENTIAL	500000.	0.446	2.000	5.989
GM	EXPONENTIAL	169188.	3.394	5.911	9.932
NS	EXPONENTIAL	*********	0.0	0.000	30.717

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	0	48924	
GF	1	1	500000	
GM	4	4	676752	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.80
NS	1	0	52400	

BURNER / CATALYTIC					IDENTIFICATION NUMBER 37
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	1886.	471.959	530.241	598.124

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	60	113156	

BUSHINGS / GENERAL			IDENTIFICATION NUMBER 38		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	88063.	8.843	11.355	14.561
GF	EXPONENTIAL	163567.	4.601	6.114	8.100
GM	EXPONENTIAL	1287441.	0.654	0.777	0.924
NS	EXPONENTIAL	1250989.	0.668	0.799	0.957
NU	EXPONENTIAL	936632.	0.440	1.068	2.284

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	15	1320948	
GF	3	12	1962806	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.81
GM	2	29	37335808	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.27
NS	3	27	33776704	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.71
NU	1	2	1873264	

CAM / GENERAL			IDENTIFICATION NUMBER 39		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	244620.	0.912	4.088	12.242
GF	EXPONENTIAL	126102.	1.770	7.930	23.748

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	244620	
GF	3	1	126104	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.65

CAMERA / MOTION (TV)			IDENTIFICATION NUMBER 40		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	7382.	83.686	135.457	214.193

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	5	36912	

CESIUM BEAM TUBE / GENERAL					IDENTIFICATION NUMBER 41
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	29174.	22.300	34.277	51.848
NS	EXPONENTIAL	29174.	22.300	34.277	51.848

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	6	175045	
NS	1	6	175045	

CIRCUIT PROTECTION DEVICE / SPARK GAP					IDENTIFICATION NUMBER 42
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	75094.	5.489	13.317	28.493
NS	EXPONENTIAL	49020.	4.553	20.400	61.092
NU	EXPONENTIAL	49020.	4.553	20.400	61.092

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	2	2	150188	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.77
NS	1	1	49020	
NU	1	1	49020	

CIRCUIT PROTECTION DEVICE / SURGE ARRESTER

IDENTIFICATION NUMBER 43

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	61310.	10.612	16.311	24.672
NS	EXPONENTIAL	395320.	1.452	2.530	4.251
NSB	EXPONENTIAL	6100.	36.589	183.936	490.944
NU	EXPONENTIAL	73530.	3.035	13.600	40.728

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	3	6	387857	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.27
NS	2	4	1581279	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.10
NSB	2	1	6100	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.37
NU	1	1	73530	

CLUTCH / FRICTION			IDENTIFICATION NUMBER 44		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	188052.	3.053	5.318	8.936
GM	EXPONENTIAL	26209.	26.593	38.155	54.278

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	4	4	752208	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.24
GM	2	8	209669	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07

CLUTCH / GENERAL					IDENTIFICATION NUMBER 45
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	197314.	1.131	5.088	15.178

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	1	197314	

COMPRESSOR / GENERAL | IDENTIFICATION NUMBER 46

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	**********	0.0	0.000	16.450
GF	EXPONENTIAL	125000.	1.785	8.000	23.958
GM	EXPONENTIAL	29741.	13.859	33.624	71.943

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	0	97848	
GF	1	1	125000	
GM	1	2	59481	

COMPRESSOR / HIGH PRESSURE					IDENTIFICATION NUMBER 47
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	1212.	774.738	824.949	878.711

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	194	235166	

COMPRESSOR / LOW PRESSURE					IDENTIFICATION NUMBER 48
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	4949.	149.846	202.076	271.479

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	11	54435	

COMPUTER MASS MEMORY / FIXED HEAD DISK			IDENTIFICATION NUMBER 49		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	5850.	128.633	170.928	228.448
NS	EXPONENTIAL	12500.	17.853	80.000	239.580

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	12	70205	
NS	1	1	12500	

COMPUTER MASS MEMORY / MAGNETIC TAPE — IDENTIFICATION NUMBER 50

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	2656.	350.806	376.459	404.150
GM	EXPONENTIAL	2520.	340.445	396.882	462.976
NS	EXPONENTIAL	9825.	70.938	101.781	144.790

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	155	411731	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.45
GM	1	36	90707	
NS	1	8	78600	

COMPUTER MASS MEMORY / MOVEABLE HEAD DISK — IDENTIFICATION NUMBER 51

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	9443.	73.811	105.904	150.655

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	8	75540	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.12

CONTROL TUBE ASSEMBLY / GENERAL — IDENTIFICATION NUMBER 52

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	9150.	55.922	109.294	200.938

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	3	27448	

CORD/CABLE		/ GENERAL			IDENTIFICATION NUMBER 53
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	180149.	3.754	5.551	8.115
GM	EXPONENTIAL	421614.	1.879	2.372	2.991
NS	EXPONENTIAL	773487.	1.007	1.293	1.658
NU	EXPONENTIAL	2270829.	0.272	0.440	0.696

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	3	7	1261040	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.48
GM	2	17	7167438	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.16
NS	3	15	11602311	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07
NU	2	5	11353145	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.10

COUNTER		/ ANALOG			IDENTIFICATION NUMBER 54
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	166667.	3.070	6.000	11.031

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	3	500000	

COUNTER / DIGITAL					IDENTIFICATION NUMBER 55
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	**********	0.0	0.000	32.899

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	0	48924	

COUNTER / MECHANICAL					IDENTIFICATION NUMBER 56
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	**********	0.0	0.000	8.157

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	0	197314	

COUNTER / WATER CLOCK			IDENTIFICATION NUMBER 57		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	18000.	34.322	55.556	87.848

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	5	90000	

COUPLING / FLEXIBLE — IDENTIFICATION NUMBER 58

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	58709.	11.082	17.033	25.765
GM	EXPONENTIAL	100125.	5.110	9.987	18.362
NS	EXPONENTIAL	10480.	21.294	95.420	285.758
NU	EXPONENTIAL	*********	0.0	0.000	614.335

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	6	352253	
GM	2	3	300376	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.34
NS	1	1	10480	
NU	1	0	2620	

COUPLING		/ FLUID			IDENTIFICATION NUMBER 59
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NSB	EXPONENTIAL	11700.	64.321	85.470	11[illegible].232

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NSB	2	12	140400	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.61

COUPLING		/ GENERAL			IDENTIFICATION NUMBER 60
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	766130.	0.538	1.305	2.793

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	2	1532259	

COUPLING	/ RIGID		IDENTIFICATION NUMBER 61		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	52838.	13.794	18.926	25.837
GF	EXPONENTIAL	500000.	1.023	2.000	3.677
GM	EXPONENTIAL	524173.	1.095	1.908	3.206
NS	EXPONENTIAL	78600.	5.244	12.723	27.222
NU	EXPONENTIAL	68670.	6.002	14.562	31.158

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	10	528379	
GF	1	3	1500000	
GM	2	4	2096690	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.45
NS	1	2	157200	
NU	2	2	137340	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.53

CRANKSHAFT / GENERAL — IDENTIFICATION NUMBER 62

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	97848.	4.212	10.220	21.867
GM	EXPONENTIAL	30038.	20.568	33.292	52.643
NU	EXPONENTIAL	**********	0.0	0.000	65.669

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	2	195696	
GM	2	5	150188	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.38
NU	1	0	24510	

CROSS HEAD	/ GENERAL				IDENTIFICATION NUMBER 63
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	13725.	30.031	72.862	155.899

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	2	27449	

DIAPHRAGMS BURST	/ GENERAL				IDENTIFICATION NUMBER 64
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	59481.	3.752	16.812	50.348
NS	EXPONENTIAL	19650.	20.975	50.891	108.887

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	59481	
NS	1	2	39300	

DIFFUSER	/ GENERAL				IDENTIFICATION NUMBER 85
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	*********	0.0	0.000	10.966

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	0	146772	

DISC ASSEMBLY	/ GENERAL				IDENTIFICATION NUMBER 86
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	2590.	340.987	386.173	437.651

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	53	137244	

DISTILLATION UNIT / FROM DISTILLING PLANT — IDENTIFICATION NUMBER 87

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	2070.	345.030	483.092	672.018

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	9	18630	

DRIVE / GEAR					IDENTIFICATION NUMBER 68
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	195696.	1.140	5.110	15.303
GF	EXPONENTIAL	166667.	3.070	6.000	11.031
GM	EXPONENTIAL	119952.	5.424	8.337	12.610
NU	EXPONENTIAL	10142.	60.915	98.600	155.912

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	195696	
GF	1	3	500000	
GM	2	8	719714	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.98
NU	2	5	50710	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.71

DRIVE / GENERAL — IDENTIFICATION NUMBER 69

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	3431.	203.130	291.449	414.605

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	8	27449	

DRIVE / VARIABLE PITCH — IDENTIFICATION NUMBER 70

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	139842.	4.836	7.151	10.454
GM	EXPONENTIAL	37547.	15.291	26.633	44.755

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	7	978897	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.34
GM	2	4	150188	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.67

DRIVE FOR COMPUTER TAPES&DISCS/ CAPSTAN MOTOR				IDENTIFICATION NUMBER 71	
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	137244.	3.728	7.286	13.396

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	3	411731	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.32

DRIVE FOR COMPUTER TAPES&DISCS/ DISCS				IDENTIFICATION NUMBER 72	
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GB	EXPONENTIAL	56313.	7.319	17.758	37.995
GF	EXPONENTIAL	43745.	13.125	22.860	38.414

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GB	1	2	112626	
GF	3	4	174980	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.81

DRIVE FOR COMPUTER TAPES&DISCS/ MAGNETIC TAPE TRANSPORT				IDENTIFICATION NUMBER 73	
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	23402.	21.865	42.732	78.563
GM	EXPONENTIAL	2520.	340.445	396.882	462.976
NS	EXPONENTIAL	26200.	19.529	38.168	70.172

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	3	70205	
GM	1	36	90707	
NS	1	3	78600	

DRIVE FOR COMPUTER TAPES&DISCS/ REEL MOTOR — IDENTIFICATION NUMBER 74

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	137245.	4.740	7.286	11.021

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	6	823472	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.18

DRIVE ROD / GENERAL — IDENTIFICATION NUMBER 75

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	*********	0.0	0.000	27.060

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	0	59481	

DRUM / GENERAL — IDENTIFICATION NUMBER 76

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	*********	0.0	0.000	12.764
GM	EXPONENTIAL	4774.	168.317	209.466	260.512

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	3	0	126104	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 1.00
GM	1	19	90707	

DUCT / GENERAL — IDENTIFICATION NUMBER 77

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	61155.	9.388	16.352	27.478
GF	EXPONENTIAL	344578.	2.023	2.902	4.128
GM	EXPONENTIAL	234353.	3.110	4.267	5.825

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	4	244620	
GF	4	8	2756624	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.38
GM	2	10	2343527	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.44

ELECTRIC HEATERS / RESISTANCE			IDENTIFICATION NUMBER 78		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	52063.	12.496	19.208	29.054
NS	EXPONENTIAL	6550.	62.926	152.672	326.862
NU	EXPONENTIAL	38765.	11.211	27.200	58.198

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	3	6	312376	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.47
NS	1	2	13100	
NU	1	2	73530	

ELECTROMECHANICAL TIMERS / GENERAL — IDENTIFICATION NUMBER 79

ENV	DIST TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	247010.	2.071	4.048	7.443
AUT	EXPONENTIAL	97848.	4.212	10.220	21.867
GF	EXPONENTIAL	211093.	4.355	4.739	5.160
GM	EXPONENTIAL	38186.	18.703	26.188	36.429
NS	EXPONENTIAL	29540.	27.683	33.852	41.400
NSB	EXPONENTIAL	34199.	6.526	29.241	87.567

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	3	741030	
AUT	1	2	195696	
GF	5	110	23210336	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.18
GM	4	9	343675	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.44
NS	2	22	649889	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.71
NSB	4	1	34200	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.66

ENGINES / GENERAL					IDENTIFICATION NUMBER 80
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	718.	1328.109	1392.106	1459.500

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	339	243516	

FEEDHORN / WAVEGUIDE					IDENTIFICATION NUMBER 81
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	19608.	41.485	51.000	62.695

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	21	411768	

FILTER / GAS (AIR) — IDENTIFICATION NUMBER 82

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	73386.	5.616	13.627	29.156
GF	EXPONENTIAL	94026.	7.412	10.635	15.129
GM	EXPONENTIAL	308449.	2.192	3.242	4.739
NS	EXPONENTIAL	129100.	3.193	7.746	16.573
NU	EXPONENTIAL	122550.	3.363	8.160	17.459

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	2	146772	
GF	4	8	752208	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07
GM	2	7	2159142	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.72
NS	2	2	258200	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07
NU	1	2	245100	

FILTER / LIQUID — IDENTIFICATION NUMBER 83

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	166667.	3.070	6.000	11.031
GM	EXPONENTIAL	66916.	10.415	14.944	21.259
ML	EXPONENTIAL	*********	SEE NOTE BELOW		
NS	EXPONENTIAL	21821.	32.730	45.827	63.748
NU	EXPONENTIAL	*********	0.0	0.000	32.835

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	3	500000	
GM	1	8	535329	
ML	1	0	18	
NS	3	9	196392	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.47
NU	1	0	49020	

NOTE: Low total part operating hours, develop failure data with caution.

FILTER / OPTICAL — IDENTIFICATION NUMBER 84

ENV	DIST TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	244620.	0.912	4.088	12.242

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	244620	

FITTINGS / GENERAL — IDENTIFICATION NUMBER 85

ENV	DIST TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	24510.	9.105	40.800	122.185
NU	EXPONENTIAL	*********	0.0	0.000	65.669

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	1	24510	
NU	1	0	24510	

FITTINGS / PERMANENT					IDENTIFICATION NUMBER 86
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	97848.	2.281	10.220	30.606
GF	EXPONENTIAL	500000.	1.023	2.000	3.677
GM	EXPONENTIAL	306751.	2.204	3.260	4.768

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	97848	
GF	1	3	1500000	
GM	2	7	2147258	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.85

FITTINGS / QUICK DISCONNECT			IDENTIFICATION NUMBER 87		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	146772.	1.520	6.813	20.404
GF	EXPONENTIAL	750000.	0.550	1.333	2.853
GM	EXPONENTIAL	79308.	6.452	12.609	23.182
NS	EXPONENTIAL	52400.	4.259	19.084	57.152

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	146772	
GF	1	2	1500000	
GM	1	3	237924	
NS	1	1	52400	

FITTINGS / THREADED — IDENTIFICATION NUMBER 88

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	195696.	1.140	5.110	15.303
GF	EXPONENTIAL	416667.	1.561	2.400	3.630
GM	EXPONENTIAL	195213.	2.941	5.123	8.608
NSB	EXPONENTIAL	6571.	102.901	152.174	222.459
NU	EXPONENTIAL	131000.	3.906	7.634	14.034

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	195696	
GF	1	6	2500000	
GM	2	4	780853	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.78
NSB	1	7	46000	
NU	1	3	393000	

FLASH LAMP / GENERAL — IDENTIFICATION NUMBER 89

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	48924.	4.561	20.440	61.212

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	48924	

FUSE HOLDER / BLOCK

IDENTIFICATION NUMBER 90

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	320772.	2.346	3.117	4.130
GM	EXPONENTIAL	250922.	0.889	3.985	11.935
NS	EXPONENTIAL	52400.	4.259	19.084	57.152
NSB	EXPONENTIAL	**********	0.0	0.000	402.389
NU	EXPONENTIAL	**********	0.0	0.000	21.890

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	4	12	3849263	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.49
GM	2	1	250924	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.74
NS	1	1	52400	
NSB	1	0	4000	
NU	1	0	73530	

FUSE HOLDER / EXTRACTOR POST — IDENTIFICATION NUMBER 91

ENV	DIST TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	250000.	1.649	4.000	8.559
GM	EXPONENTIAL	**********	0.0	0.000	6.765
NS	EXPONENTIAL	98040.	2.276	10.200	30.546

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	2	500000	
GM	1	0	237924	
NS	1	1	98040	

FUSE HOLDER / PLUG

IDENTIFICATION NUMBER 92

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	300000.	1.374	3.333	7.132
GM	EXPONENTIAL	602404.	0.370	1.660	4.971
NS	EXPONENTIAL	1415465.	0.539	0.708	0.925

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	2	600000	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.28
GM	2	1	[illegible]2410	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.87
NS	2	13	18401056	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.06

GAS DRYER DESICATOR / MOLECULAR SIEVE — IDENTIFICATION NUMBER 93

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	13100.	17.035	76.336	228.607

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	1	13100	

GASKETS & SEALS / DYNAMIC — IDENTIFICATION NUMBER 94

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	110511.	7.169	9.049	11.412
GF	EXPONENTIAL	303450.	2.444	3.295	4.427
GM	EXPONENTIAL	215369.	3.140	4.643	6.788
NS	EXPONENTIAL	520196.	1.425	1.922	2.583
NSB	EXPONENTIAL	46000.	4.851	21.739	65.103
NU	EXPONENTIAL	315118.	1.308	3.173	6.790

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	17	1878881	
GF	4	11	3337948	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.16
GM	3	7	1507580	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.06
NS	4	11	5722160	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.29
NSB	1	1	46000	
NU	2	2	630240	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.86

GASKETS & SEALS / STATIC — IDENTIFICATION NUMBER 95

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AIF	EXPONENTIAL	137155.	1.627	7.291	21.835
AUT	EXPONENTIAL	108385.	7.681	9.226	11.087
GF	EXPONENTIAL	332896.	2.031	3.004	4.391
GM	EXPONENTIAL	246955.	2.951	4.049	5.528
NS	EXPONENTIAL	546846.	1.488	1.829	2.248
NSB	EXPONENTIAL	46000.	4.851	21.739	65.103
NU	EXPONENTIAL	716918.	0.801	1.395	2.344

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AIF	1	1	137155	
AUT	1	26	2818022	
GF	4	7	2330272	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.58
GM	3	10	2469547	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.13
NS	4	21	11483769	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.27
NSB	1	1	46000	
NU	1	4	2867670	

GEAR / ANTIROTATION					IDENTIFICATION NUMBER 96
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	633.	807.898	1578.948	2802.893

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	1900	

GEAR / BEVEL — IDENTIFICATION NUMBER 97

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AIF	EXPONENTIAL	68578.	6.010	14.582	31.200
AUT	EXPONENTIAL	146772.	2.808	6.813	14.578
GF	EXPONENTIAL	750000.	0.550	1.333	2.853
GM	EXPONENTIAL	340030.	1.505	2.941	5.407
NS	EXPONENTIAL	104800.	2.129	9.542	28.576
NU	EXPONENTIAL	320317.	0.697	3.122	9.349

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AIF	1	2	137155	
AUT	1	2	293544	
GF	1	2	1500000	
GM	2	3	1020090	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.64
NS	1	1	104800	
NU	2	1	320320	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.68

GEAR / HELICAL			IDENTIFICATION NUMBER 98		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	146772.	2.808	6.813	14.578
GF	EXPONENTIAL	200000.	1.116	5.000	14.974
GM	EXPONENTIAL	50696.	10.093	19.725	36.265
NS	EXPONENTIAL	*********	0.0	0.000	13.134

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	2	293544	
GF	1	1	200000	
GM	3	3	152088	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.08
NS	1	0	122550	

GEAR / HYPOID — IDENTIFICATION NUMBER 99

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	200000.	1.116	5.000	14.974

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	1	200000	

GEAR / SPUR			IDENTIFICATION NUMBER 100		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	852054.	0.725	1.174	1.856
AUT	EXPONENTIAL	78278.	7.892	12.775	20.200
GF	EXPONENTIAL	317244.	2.132	3.152	4.608
GM	EXPONENTIAL	168077.	3.676	5.950	9.408
NS	EXPONENTIAL	104800.	3.933	9.542	20.416
NU	EXPONENTIAL	199458.	1.119	5.014	15.014

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	5	4260268	
AUT	1	5	391392	
GF	4	7	2220710	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.45
GM	3	5	840386	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.75
NS	1	2	209600	
NU	2	1	199460	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.10

GEAR / WORM			IDENTIFICATION NUMBER 101		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	*********	0.0	0.000	8.048
GM	EXPONENTIAL	*********	0.0	0.000	26.223

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	0	200000	
GM	2	0	61381	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.99

GEAR BOX / MULTIPLIER — IDENTIFICATION NUMBER 107

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	463.	2071.857	2159.230	2250.676
GF	EXPONENTIAL	**********	0.0	0.000	16.096

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	437	202387	
GF	1	0	100000	

GEAR BOX / REDUCTION — IDENTIFICATION NUMBER 103

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	146772.	2.808	6.813	14.578
GF	EXPONENTIAL	200000.	1.116	5.000	14.974
GM	EXPONENTIAL	53320.	10.768	18.755	31.516
NS	EXPONENTIAL	51969.	13.411	19.242	27.373
NU	EXPONENTIAL	62119.	3.593	16.098	48.209

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	2	293544	
GF	1	1	200000	
GM	4	4	213279	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.16
NS	1	8	415750	
NU	2	1	62120	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.49

GEAR TRAIN	/ BEVEL				IDENTIFICATION NUMBER 104
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	172025.	5.126	5.813	6.596

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	52	8945282	

GENERATOR	/ AC				IDENTIFICATION NUMBER 105
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	104834.	3.932	9.539	20.410

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	2	2	209669	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.13

GENERATOR / GENERAL (OXYGEN GENERATOR)					IDENTIFICATION NUMBER 106
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	526.	1759.922	1900.320	2052.836

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	132	69462	

GLASS (SIGHT GAUGE) / GENERAL					IDENTIFICATION NUMBER 107
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	2287.	328.998	437.174	579.174

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	12	27449	

GROMMET / GENERAL | IDENTIFICATION NUMBER 108

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	293544.	0.760	3.407	10.202

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	293544	

GIMBALS / GENERAL — IDENTIFICATION NUMBER 109

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	48924.	8.425	20.440	43.734
ML	EXPONENTIAL	*********	SEE NOTE BELOW		
NU	EXPONENTIAL	49020.	4.553	20.400	61.092

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	2	97848	
ML	1	0	10	
NU	1	1	49020	

NOTE; Low total part operating hours develop failure data with caution

GIMBALS / TORQUE					IDENTIFICATION NUMBER 110
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	193637.	3.599	5.164	7.347

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	8	1549092	

GYROSCOPE / SINGLE AXIS					IDENTIFICATION NUMBER 111
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	2224.	391.885	449.877	516.352

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	44	97848	

GYROSCOPE / TWO AXIS ROTOR					IDENTIFICATION NUMBER 112
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	20234.	42.919	49.422	56.949

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	42	849826	

HEAT EXCHANGERS / COPLATES					IDENTIFICATION NUMBER 113.
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	90707.	5.641	11.025	20.269

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	272121	

HEAT EXCHANGERS / GENERAL — IDENTIFICATION NUMBER 114

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	36693.	20.510	27.253	36.105
GF	EXPONENTIAL	312500.	1.319	3.200	6.847
NS	EXPONENTIAL	72495.	11.157	13.794	17.052

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	12	440316	
GF	1	2	625000	
NS	2	20	1449899	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.18

HEAT EXCHANGERS		/ RADIATOR			IDENTIFICATION NUMBER 115
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	178443.	2.310	5.604	11.991
NS	EXPONENTIAL	4000.	154.450	250.000	395.314

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	356886	
NS	1	5	20000	

HEATER		/ WATER			IDENTIFICATION NUMBER 118
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	2368.	363.796	422.222	490.362

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	38	90000	

HEATER BLANKETS / GENERAL — IDENTIFICATION NUMBER 117

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	97848.	2.281	10.220	30.606

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	97848	

HEATER, FLEX ELEMENT / HEATER TAPE — IDENTIFICATION NUMBER 118

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	1358145.	0.423	0.736	1.237

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	4	5432580	

HIGH SPEED PRINTER / ELECTROSTATIC				IDENTIFICATION NUMBER 119	
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	1417.	630.498	705.568	790.100

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	64	90707	

HIGH SPEED PRINTER / IMPACT

IDENTIFICATION NUMBER 120

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GB	EXPONENTIAL	112626.	1.981	8.879	28.590
GF	EXPONENTIAL	3269.	226.851	305.921	410.990
NS	EXPONENTIAL	11503.	44.480	86.931	159.823

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GB	1	1	112626	
GF	2	11	35957	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.13
NS	2	3	34510	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.18

HIGH SPEED PRINTER / THERMAL — IDENTIFICATION NUMBER 121

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	34049.	22.102	29.370	38.909

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	12	408583	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.67

HOSE / FLEXIBLE — IDENTIFICATION NUMBER 122

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NSB	EXPONENTIAL	18600.	39.185	53.763	73.397

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NSB	1	10	186000	

HOSE / FLEXIBLE, PROPELLANT — IDENTIFICATION NUMBER 123

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ML	EXPONENTIAL	**********	SEE NOTE BELOW		

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ML	1	0	27	

NOTE: Low total part operating hours, develop failure data with caution

HOSE / GENERAL — IDENTIFICATION NUMBER 124

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	288656.	2.607	3.464	4.590
GM	EXPONENTIAL	225390.	3.000	4.437	6.486
NS	EXPONENTIAL	224538.	3.181	4.454	6.195
NU	EXPONENTIAL	77340.	5.329	12.930	27.665

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	4	12	3463872	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.40
GM	2	7	1577732	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.41
NS	4	9	2020839	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.17
NU	3	2	154680	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.47

HOUSING	/ GENERAL		IDENTIFICATION NUMBER 125		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	3580.	229.535	279.309	339.940

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	23	82346	

INCINERATOR	/ FROM SEWAGE TREATMENT		IDENTIFICATION NUMBER 128		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	492.	838.583	2034.588	4353.273

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	2	983	

INSTRUMENTS / AMMETER — IDENTIFICATION NUMBER 127

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	125000.	1.785	8.000	23.958
GM	EXPONENTIAL	75819.	5.436	13.189	28.220
NS	EXPONENTIAL	132526.	5.595	7.546	10.137
NSB	EXPONENTIAL	**********	0.0	0.000	98.145

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	1	125000	
GM	3	2	151638	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.94
NS	4	11	1457787	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.80
NSB	2	0	16400	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 1.00

INSTRUMENTS / FLOW METER — IDENTIFICATION NUMBER 128

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	63333.	8.079	15.789	29.029
NS	EXPONENTIAL	19525.	29.406	51.216	88.065
NSB	EXPONENTIAL	4800.	148.794	208.334	289.807
NU	EXPONENTIAL	15000.	14.878	66.667	199.650

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	3	190000	
NS	2	4	78100	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.68
NSB	3	9	43200	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.15
NU	1	1	15000	

INSTRUMENTS / HUMIDITY INDICATOR — IDENTIFICATION NUMBER 129

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	48924.	4.561	20.440	61.212

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	48924	

INSTRUMENTS / INDICATOR					IDENTIFICATION NUMBER 130
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	925.	958.565	1081.666	1221.415
GF	EXPONENTIAL	242713.	2.108	4.120	7.575
NS	EXPONENTIAL	16340.	31.314	61.199	112.515

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	56	51772	
GF	1	3	728140	
NS	1	3	49020	

INSTRUMENTS / INDICATOR (LIGHT) — IDENTIFICATION NUMBER 131

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	766130.	0.538	1.305	2.793

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	2	1532259	

INSTRUMENTS / INDICATOR(FLUID LEVEL) — IDENTIFICATION NUMBER 132

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	1260.	406.086	793.651	1459.126

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	3780	

INSTRUMENTS / PRESSURE GAUGE — IDENTIFICATION NUMBER 133

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	24462.	26.596	40.880	61.836

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	6	146772	

INSTRUMENTS / TIME METER — IDENTIFICATION NUMBER 134

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	383065.	1.499	2.611	4.387

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	4	1532259	

INSTRUMENTS / TOTAL TIME METER | IDENTIFICATION NUMBER 135

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	58369.	14.955	17.132	19.640

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	45	2626598	

INSTRUMENTS / VOLTMETER					IDENTIFICATION NUMBER 136
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	266458.	1.547	3.753	8.030
GM	EXPONENTIAL	:04458.	4.898	9.573	17.600
NS	EXPONENTIAL	586924.	1.053	1.704	2.694
NSB	EXPONENTIAL	*********	0.0	0.000	30.142

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	2	532916	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.68
GM	3	3	313376	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.86
NS	5	5	2934631	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.74
NSB	3	0	53400	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 1.00

JOINT, MICROWAVE ROTARY / GENERAL — IDENTIFICATION NUMBER 137

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	3550.	259.500	281.712	305.975
GF	EXPONENTIAL	41667.	12.280	24.000	44.124
GM	EXPONENTIAL	126941.	4.867	7.878	12.457
NU	EXPONENTIAL	20707.	24.710	48.294	88.788

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	116	411768	
GF	1	3	125000	
GM	3	5	634707	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.72
NU	2	3	62120	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.62

KEYBOARD	/ ELECTROMECHANICAL			IDENTIFICATION NUMBER 138	
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AIT	EXPONENTIAL	75000.	2.976	13.333	39.930
GB	EXPONENTIAL	112626.	1.981	8.879	26.590
NS	EXPONENTIAL	47609.	4.688	21.004	62.902
NSB	EXPONENTIAL	*********	0.0	0.000	804.779

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AIT	1	1	75000	
GB	1	1	112626	
NS	3	1	47610	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.28
NSB	1	0	2000	

KEYBOARD	/ GENERAL			IDENTIFICATION NUMBER 139	
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	144741.	4.495	6.909	10.451

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	6	868447	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.19

KEYBOARD	/ MECHANICAL			IDENTIFICATION NUMBER 140	
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	214323.	2.679	4.666	7.841
GM	EXPONENTIAL	7509.	107.707	133.1[illegible]5	164.821

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	4	857290	
GM	2	20	150188	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.17

KNOB / GENERAL — IDENTIFICATION NUMBER 141

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	16308.	48.942	61.320	76.782
GF	EXPONENTIAL	480622.	0.858	2.081	4.452
NS	EXPONENTIAL	1384822.	0.298	0.722	1.545
NSB	EXPONENTIAL	10200.	40.409	98.040	209.769
NU	EXPONENTIAL	**********	0.0	0.000	21.890

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	18	293544	
GF	2	2	961243	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.14
NS	2	2	2769659	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.54
NSB	2	2	20400	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.35
NU	1	0	73530	

LAMP / XENON — IDENTIFICATION NUMBER 142

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	130.	6503.187	7704.156	9131.840

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	30	3894	

LAMP HOLDER / GENERAL | IDENTIFICATION NUMBER 143

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	24462.	16.849	40.880	87.468
GF	EXPONENTIAL	220268.	3.242	4.540	6.315
NS	EXPONENTIAL	631139.	0.910	1.584	2.663
NSB	EXPONENTIAL	20667.	31.480	48.387	73.192

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	2	48924	
GF	2	9	1982414	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.71
NS	1	4	2524554	
NSB	1	6	124000	

LENS	/ OPTICAL		IDENTIFICATION NUMBER 144		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	*********	0.0	0.000	2.742

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	0	587088	

LOW SPEED PRINTER	/ DOT MATRIX		IDENTIFICATION NUMBER 145		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	3076.	244.854	325.097	430.693

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	12	36912	

MANIFOLD		/ GENERAL	IDENTIFICATION NUMBER 146		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	97848.	4.212	10.220	21.867
GF	EXPONENTIAL	750000.	0.550	1.333	2.853
ML	EXPONENTIAL	*********	SEE NOTE BELOW		
NS	EXPONENTIAL	766130.	0.538	1.305	2.793
NSB	EXPONENTIAL	155000.	3.704	6.452	10.841
NU	EXPONENTIAL	*********	0.0	0.000	65.669

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	2	195696	
GF	1	2	1500000	
ML	1	0	76	
NS	1	2	1532259	
NSB	1	4	620000	
NU	1	0	24510	

NOTE: Low total part operating hours, develop failure data with caution

METAL TUBING / GENERAL

IDENTIFICATION NUMBER 147

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	6666666.	0.077	0.150	0.278
GM	EXPONENTIAL	1371027.	0.301	0.729	1.581
NS	EXPONENTIAL	829984.	0.744	1.205	1.905
NU	EXPONENTIAL	1643844.	0.136	0.608	1.822

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	3	20000000	
GM	2	2	2742068	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.45
NS	2	5	4149919	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.96
NU	2	1	1643860	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.86

MODULES / GENERAL					IDENTIFICATION NUMBER 148
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	1794.	521.754	557.491	595.895

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	175	313906	

MOTOR GENERATOR SET / AC					IDENTIFICATION NUMBER 149
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	*********	0.0	0.000	425.809
NS	EXPONENTIAL	13100.	17.035	76.336	228.607

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	0	3780	
NS	1	1	13100	

MOTOR GENERATOR SET / DC — IDENTIFICATION NUMBER 150

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	26200.	8.518	38.168	114.303

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	1	26200	

MOTOR GENERATOR SET / GENERAL — IDENTIFICATION NUMBER 151

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	39395.	22.261	25.384	28.964

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	48	1890976	

MOTOR, ELECTRIC / > 1 HORSE POWER, AC — IDENTIFICATION NUMBER 152

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	750000.	0.550	1.333	2.853
GM	EXPONENTIAL	36240.	11.373	27.594	59.040
NS	EXPONENTIAL	24274	35.778	41.196	47.470
NU	EXPONENTIAL	8170.	62.628	122.399	225.030

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	2	1500000	
GM	2	2	72481	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.37
NS	1	42	1019520	
NU	1	3	24510	

MOTOR, ELECTRIC / > 10 HORSE POWER, AC — IDENTIFICATION NUMBER 153

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	90000.	2.480	11.111	33.275

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	1	90000	

MOTOR, ELECTRIC / DC — IDENTIFICATION NUMBER 154

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	54024.	14.110	18.510	24.225

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	2	13	702310	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.67

MOTOR, ELECTRIC / DC, (4 HORSEPOWER) — IDENTIFICATION NUMBER 155

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GB	EXPONENTIAL	*********	0.0	0.000	83.323

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GB	1	0	19317	

MOTOR, ELECTRIC / HYDRAULIC, DC — IDENTIFICATION NUMBER 156

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	16308.	39.894	61.320	92.754
GF	EXPONENTIAL	90000.	2.480	11.111	33.275

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	6	97848	
GF	1	1	90000	

MOTOR, ELECTRIC / SERVO, DC			IDENTIFICATION NUMBER 157		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AIF	EXPONENTIAL	34289.	16.745	29.164	49.008
ARW	EXPONENTIAL	81928.	10.161	12.206	14.668
AUT	EXPONENTIAL	65232.	7.844	15.330	28.184
GF	EXPONENTIAL	99425.	7.183	10.058	13.991
GM	EXPONENTIAL	31520.	19.601	31.726	50.168
NU	EXPONENTIAL	**********	0.0	0.000	65.669

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AIF	1	4	137155	
ARW	1	26	2130134	
AUT	1	3	195696	
GF	1	9	894826	
GM	4	5	157598	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.53
NU	1	0	24510	

MOTOR, ELECTRIC / STEPPER | IDENTIFICATION NUMBER 158

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	125215.	6.219	7.986	10.240
GM	EXPONENTIAL	75094.	5.489	13.317	28.493

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	15	1878222	
GM	2	2	150188	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.77

O-RING / GENERAL					IDENTIFICATION NUMBER 159
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	56723.	15.823	17.629	19.654
GM	EXPONENTIAL	3780.	59.038	264.550	792.261

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	69	3913920	
GM	1	1	3780	

PARTICLE SEPARATOR / GENERAL					IDENTIFICATION NUMBER 160
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	1085.	858.023	921.659	990.418

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	151	163835	

PITCH HORN	/ GENERAL	IDENTIFICATION NUMBER 161

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	2287.	383.404	437.178	498.845

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	48	109795	

PLOTTER	/ ELECTROMECHANICAL	IDENTIFICATION NUMBER 162

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	144730.	4.816	6.909	9.828

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	8	1157842	

POWER CIRCUIT BREAKER / CURRENT & VOLTAGE TRIP — IDENTIFICATION NUMBER 163

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	100707.	7.363	9.930	13.340
NS	EXPONENTIAL	16667.	46.726	60.000	76.935
NSB	EXPONENTIAL	37999.	5.874	26.317	78.810

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	11	1107781	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.62
NS	1	15	250000	
NSB	4	1	38000	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.62

POWER CIRCUIT BREAKER / CURRENT TRIP					IDENTIFICATION NUMBER 164
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	243017.	2.542	4.115	6.507
GM	EXPONENTIAL	154105.	5.214	6.489	8.070
NS	EXPONENTIAL	357597.	1.819	2.796	4.230
NU	EXPONENTIAL	355395.	1.16[illegible]	2.814	6.020

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	3	5	1215091	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.38
GM	3	19	2927995	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07
NS	2	6	2145579	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.06
NU	1	2	710790	

POWEP SWITCH GEAR / GENERAL — IDENTIFICATION NUMBER 165

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	250000.	0.893	4.000	11.979
GM	EXPONENTIAL	304150.	0.734	3.288	9.846
NU	EXPONENTIAL	**********	0.0	0.000	65.669

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	1	250000	
GM	3	1	304156	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.60
NU	1	0	24510	

PRECIPITATOR / ELECTROSTATIC — IDENTIFICATION NUMBER 166

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	2777.	184.230	360.057	661.965

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	3	8332	

PRISM / OPTICAL — IDENTIFICATION NUMBER 167

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	*********	0.0	0.000	10.966

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	0	146772	

PROPELLER / GENERAL (FROM SHIP) IDENTIFICATION NUMBER 168

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	1120.	368.167	893.256	1911.242

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	2	2239	

PROPORTIONING UNIT / FROM DISTILLING PLANT IDENTIFICATION NUMBER 169

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	*********	0.0	0.000	102.357

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	0	15725	

PULLEY / GEAR BELT					IDENTIFICATION NUMBER 170
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	189156.	3.439	5.287	7.997

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	3	6	1134936	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.23

PULLEY / GROOVED					IDENTIFICATION NUMBER 171
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	80298.	6.372	12.454	22.896
NS	EXPONENTIAL	766130.	0.538	1.305	2.793

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	2	3	240895	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.74
NS	1	2	1532259	

PULLEY / V-PULLEY					IDENTIFICATION NUMBER 172
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	79308.	6.452	12.609	23.182

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	237924	

PUMP / CENTRIFUGAL					IDENTIFICATION NUMBER 173
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	26825.	32.693	37.279	42.537

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	48	1287605	

PUMP / HYDRAULIC — IDENTIFICATION NUMBER 174

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	48924.	4.561	20.440	61.212
GF	EXPONENTIAL	68000.	9.085	14.706	23.254
GM	EXPONENTIAL	473.	1475.055	2116.402	3010.715
NS	EXPONENTIAL	17700.	28.908	56.497	103.870

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	48924	
GF	2	5	340000	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.12
GM	1	8	3780	
NS	2	3	53100	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.74

PUMP / HYDRAULIC(ROTARY)			IDENTIFICATION NUMBER 175		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NU	EXPONENTIAL	24510.	9.105	40.800	122.185

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NU	1	1	24510	

PUMP / PNEUMATIC			IDENTIFICATION NUMBER 176		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	106153.	4.820	9.420	17.319
GM	EXPONENTIAL	19827.	25.807	50.436	92.727

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	3	318459	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.86
GM	1	3	59481	

PUMP / ROTARY — IDENTIFICATION NUMBER 177

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	3667.	60.857	272.702	818.875

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	1	3667	

PUMP / VACUUM — IDENTIFICATION NUMBER 178

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	94250.	5.429	10.610	18.507

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	3	3	282750	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.45

PUMP / VACUUM - LOBE TYPE | IDENTIFICATION NUMBER 179

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	4091.	199.898	244.444	298.946

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	22	90000	

PUMP / VACUUM - RING SEAL TYPE | IDENTIFICATION NUMBER 180

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	90000.	2.480	11.111	33.275

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	1	90000	

PURIFIER / CENTRIFUGAL — IDENTIFICATION NUMBER 181

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	655.	1033.057	1527.717	2233.328

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	7	4582	

QUILL ASSEMBLY / GENERAL — IDENTIFICATION NUMBER 182

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	771.	1186.734	1296.933	1418.125

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	100	77105	

RADOME		/ MICROWAVE, ANTENNA		IDENTIFICATION NUMBER 183	
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AIF	EXPONENTIAL	137155.	3.005	7.291	15.800

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AIF	1	2	274310	

REFRIGERATION PLANT		/ FROM AIR CONDITIONG PLANT		IDENTIFICATION NUMBER 184	
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	9337.	95.233	107.106	120.541

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	59	550856	

REGULATOR / ELECTRICAL					IDENTIFICATION NUMBER 185
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	377134.	1.093	2.652	5.873

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	2	754268	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.46

REGULATOR / PNEUMATIC (PRESSURE)					IDENTIFICATION NUMBER 186
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	6429.	119.929	155.556	201.397

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	14	90000	

REGULATOR / PNEUMATIC (VACUUM BREAKER)			IDENTIFICATION NUMBER 187		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	9000.	80.982	111.111	151.687

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	10	90000	

REGULATOR / PRESSURE			IDENTIFICATION NUMBER 188		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	97848.	2.281	10.220	30.806
GF	EXPONENTIAL	500000.	1.023	2.000	3.677
GM	EXPONENTIAL	97771.	5.872	10.228	17.187
ML	EXPONENTIAL	*********	SEE NOTE BELOW		
NS	EXPONENTIAL	34040.	15.031	29.377	54.010

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	97848	
GF	1	3	1500000	
GM	2	4	391083	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.81
ML	1	0	216	
NS	3	3	102120	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.13

NOTE: Low total part operating hours, develop failure data with caution

REGULATOR / TEMPERATURE			IDENTIFICATION NUMBER 189		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	4535	90.885	220.507	471.805
NS	EXPONENTIAL	13100.	17.035	76.336	228.607

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	9070	
NS	1	1	13100	

RESILIENT MOUNT / GENERAL — IDENTIFICATION NUMBER 190

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	330237.	1.739	3.028	5.089
GF	EXPONENTIAL	250000.	2.297	4.000	6.722
GM	EXPONENTIAL	34166.	21.704	29.269	39.321
NS	EXPONENTIAL	772117.	0.744	1.295	2.176
NSB	EXPONENTIAL	12300.	33.509	81.301	173.954
NU	EXPONENTIAL	424840.	1.204	2.354	4.328

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	4	1320948	
GF	1	4	1000000	
GM	2	11	375828	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.39
NS	2	4	3088468	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.83
NSB	1	2	24600	
NU	1	3	1274520	

RESILIENT MOUNT / SHOCK MOUNTS — IDENTIFICATION NUMBER 191

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	5600.	91.369	178.571	328.303

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	16800	

RETAINING RING / GENERAL — IDENTIFICATION NUMBER 192

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	15759.	59.726	63.455	67.439
GF	EXPONENTIAL	612693.	1.104	1.632	2.386
GM	EXPONENTIAL	391925.	1.822	2.552	3.549
NS	EXPONENTIAL	1474697.	0.347	0.678	1.247
NU	EXPONENTIAL	339590.	1.214	2.945	6.301

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	208	3277908	
GF	4	7	4288853	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.37
GM	3	9	3527328	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.58
NS	2	3	4424091	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.41
NU	2	2	679180	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.09

SEAL / GENERAL — IDENTIFICATION NUMBER 193

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	1961.	393.223	510.037	660.340

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	14	27449	

SEAL / SOLDER — IDENTIFICATION NUMBER 194

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	460402.	1.583	2.172	2.965

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	10	4604017	

SENSORS / WATER LEVEL — IDENTIFICATION NUMBER 195

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	12857.	52.594	77.778	113.701

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	7	90000	

SENSORS/TRANSDUCER/TRANSMITTER/ ACOUSTIC (HYDROPHONES) — IDENTIFICATION NUMBER 198

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS?	EXPONENTIAL	*********	0.0	0.000	184.244

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NSB	1	0	8736	

SENSORS/TRANSDUCER/TRANSMITTER/ AIRFLOW — IDENTIFICATION NUMBER 197

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	1900.	216.928	526.316	1126.124

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	3800	

SENSORS/TRANSDUCER/TRANSMITTER/ FLOW (LIQUID) — IDENTIFICATION NUMBER 198

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	98657.	4.178	10.136	21.688
GM	EXPONENTIAL	95764.	7.611	10.442	14.258
NS	EXPONENTIAL	36765.	11.211	27.200	58.198
NU	EXPONENTIAL	39300.	5.678	25.445	76.202

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	2	197314	
GM	2	10	957638	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.16
NS	1	2	73530	
NU	1	1	39300	

SENSORS/TRANSDUCER/TRANSMITTER/ HUMIDITY			IDENTIFICATION NUMBER 199		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	48924.	4.561	20.440	61.212

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	48924	

SENSORS/TRANSDUCER/TRANSMITTER/ INFRARED			IDENTIFICATION NUMBER 200		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	1553.	574.805	643.855	721.681

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	63	97848	

SENSORS/TRANSDUCER/TRANSMITTER/ MOTION					IDENTIFICATION NUMBER 201
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	10728.	71.867	93.217	120.687
NS	EXPONENTIAL	*********	0.0	0.000	65.669

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	2	14	150188	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.80
NS	1	0	24510	

SENSORS/TRANSDUCER/TRANSMITTER/ PRESSURE					IDENTIFICATION NUMBER 202
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	24462.	26.596	40.880	61.836
GF	EXPONENTIAL	5201.	172.717	192.271	214.175
GM	EXPONENTIAL	1890.	218.076	529.100	1132.082
NS	EXPONENTIAL	43315.	9.515	23.087	49.397
NSB	EXPONENTIAL	364.	613.087	2747.252	8227.320

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	6	146772	
GF	1	70	364070	
GM	1	2	3780	
NS	2	2	86630	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.25
NSB	1	1	364	

SENSORS/TRANSDUCER/TRANSMITTER/ TEMPERATURE					IDENTIFICATION NUMBER 203
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	97848.	4.212	10.220	21.867
GF	EXPONENTIAL	15763.	44.215	63.440	90.247
GM	EXPONENTIAL	75342.	9.989	13.273	17.584
NS	EXPONENTIAL	63809.	3.498	15.672	46.932
NSB	EXPONENTIAL	34073.	18.132	29.349	46.408

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	2	195696	
GF	3	8	126104	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.21
GM	2	12	904099	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.78
NS	2	1	63810	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.32
NSB	3	5	170364	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.30

SHAFT		/ GENERAL		IDENTIFICATION NUMBER 204	
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	3431.	240.616	291.453	353.124
AUT	EXPONENTIAL	207927.	2.761	4.809	8.082
GF	EXPONENTIAL	186771.	3.824	5.354	7.448
GM	EXPONENTIAL	80642.	9.453	12.401	16.229
NU	EXPONENTIAL	99729.	2.238	10.027	30.029

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	24	82346	
AUT	1	4	831708	
GF	4	9	1680937	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.97
GM	2	13	1048345	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.06
NU	2	1	99730	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.44

SHOCK ABSORBERS	/ COMBINATION				IDENTIFICATICN NUMBER 205
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	73386.	5.616	13.627	29.156
GM	EXPONENTIAL	52417.	13.296	19.078	27.139

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	2	146772	
GM	2	8	419338	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07

SHOCK ABSORBERS / RISILIENT — IDENTIFICATION NUMBER 206

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	52417.	10.953	19.078	32.059
NU	EXPONENTIAL	122550.	4.175	8.160	15.002

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	2	4	209669	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.79
NU	1	3	367650	

SLIP RING-BRUSH		/ POWER & SIGNAL		IDENTIFICATION NUMBER 207	
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	1760462	0.421	0.568	0.763

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	11	19365088	

SLIP RINGS		/ GENERAL		IDENTIFICATION NUMBER 208	
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	1500000.	0.149	0.667	1.996
GM	EXPONENTIAL	3800.	171.209	263.158	398.061
NS	EXPONENTIAL	73530.	3.035	13.600	40.728

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	1	1500000	
GM	1	6	22800	
NS	1	1	73530	

SOLENOIDS	/ GENERAL					IDENTIFICATION NUMBER 209
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND	
NS	EXPONENTIAL	24510.	9.105	40.800	122.185	

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	1	24510	

SOLENOIDS / LINEAR			IDENTIFICATION NUMBER 210		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	90000.	2.480	11.111	33.275
GM	EXPONENTIAL	50379.	12.914	19.849	30.025
NS	EXPONENTIAL	32750.	12.585	30.534	85.332

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	1	90000	
GM	3	6	302276	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.06
NS	1	2	65500	

SOLENOIDS	/ ROTARY		IDENTIFICATION NUMBER 211		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	29493.	20.947	33.906	53.614

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	3	5	147466	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.88

SPRING	/ COMPRESSION		IDENTIFICATION NUMBER 212		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	91812.	6.254	10.892	18.303

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	4	367248	

SPRING		/ GENERAL			IDENTIFICATION NUMBER 213
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AIF	EXPONENTIAL	45718.	11.192	21.873	40.214

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AIF	1	3	137155	

SPRING		/ TORRISION			IDENTIFICATION NUMBER 214
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	69952.	7.315	14.296	26.282

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	3	209856	

SPROCKET / GENERAL			IDENTIFICATION NUMBER 215		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	244620.	0.912	4.088	12.242
GF	EXPONENTIAL	175662.	3.517	5.693	9.002

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	1	244620	
GF	4	5	878312	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.50

STEAMBOILER / GENERAL (FROM SHIP)			IDENTIFICATION NUMBER 216		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	1958.	378.790	510.820	686.262

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	11	21534	

STOW PIN / GENERAL			IDENTIFICATION NUMBER 217		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NU	EXPONENTIAL	163400.	3.131	6.120	11.252

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NU	1	3	490200	

SWITCH / COAXIAL (ELECTROMECHANICAL)			IDENTIFICATION NUMBER 218		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	27780.	26.236	35.997	49.143

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	10	277800	

SWITCH / FLOW (LIQUID)			IDENTIFICATION NUMBER 219		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	133992.	4.285	7.463	12.541
NS	EXPONENTIAL	198017.	3.415	5.050	7.383
NU	EXPONENTIAL	10480.	39.329	95.420	204.164

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	2	4	535968	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.21
NS	3	7	1386117	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.06
NU	1	2	20960	

SWITCH / INTERLOCK — IDENTIFICATION NUMBER 220

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	1583.	410.902	631.579	955.348

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	6	9500	

SWITCH / PRESSURE (AIR FLOW)					IDENTIFICATION NUMBER 221
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	239465.	2.983	4.176	5.809
GM	EXPONENTIAL	90047.	7.932	11.105	15.448
ML	EXPONENTIAL	*********	SEE NOTE BELOW		
NS	EXPONENTIAL	110582.	7.792	9.043	10.502
NU	EXPONENTIAL	40000.	5.579	25.000	74.869

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	5	9	2155190	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.83
GM	2	9	810421	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.51
ML	1	0	164	
NS	4	38	4202120	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.33
NU	1	1	40000	

NOTE: Low total part operating hours, develop failure data with caution

SWITCH / ROCKER			IDENTIFICATION NUMBER 222		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	95067.	8.452	10.519	13.082

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	19	1806280	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.46

SWITCH / THERMOSTATIC			IDENTIFICATION NUMBER 223		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	61155.	9.388	16.352	27.478
GF	EXPONENTIAL	205556.	3.475	4.865	6.767
GM	EXPONENTIAL	63101.	13.024	15.848	19.288
NS	EXPONENTIAL	334866.	2.383	2.986	3.739
NSB	EXPONENTIAL	18232.	44.075	54.850	68.217
NU	EXPONENTIAL	66730.	7.668	14.986	27.551

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	4	244620	
GF	2	9	1850000	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.08
GM	1	23	1451312	
NS	3	18	6027596	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.73
NSB	4	19	346400	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.75
NU	3	3	200190	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.48

SWITCH / THUMBWHEEL			IDENTIFICATION NUMBER 224		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	249616.	2.792	4.006	5.699
GM	EXPONENTIAL	3780.	59.038	264.550	792.261

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PAR. OPERATING HOURS	COMMENTS
GF	3	8	1996924	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.32
GM	1	1	3780	

SWITCH / WAVE GUIDE			IDENTIFICATION NUMBER 225		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	250000.	1.649	4.000	8.559
GM	EXPONENTIAL	19827.	25.807	50.436	92.727
NS	EXPONENTIAL	15400.	33.225	64.935	119.383

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	2	500000	
GM	1	3	59481	
NS	2	3	46200	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.42

SWITCHBOARD CONTROL / FROM OXYGEN GENERATOR			IDENTIFICATION NUMBER 226		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	1670.	542.640	598.877	661.336

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	82	136923	

SYNCRO / TRANSMITTER — IDENTIFICATION NUMBER 227

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	193115.	3.502	5.178	7.570

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	7	1351805	

SYNCRO ASSEMBLY / GENERAL — IDENTIFICATION NUMBER 228

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	21882.	36.723	45.701	56.838

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	19	415750	

SYNCRO/RESOLVER	/ LOW SPEED LOW LOAD		IDENTIFICATION NUMBER 229		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUF	EXPONENTIAL	774546.	0.532	1.291	2.782

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUF	1	2	1549092	

TACHOMETER	/ GENERAL		IDENTIFICATION NUMBER 230		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	16308.	43.795	61.320	85.300

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	9	146772	

TANK / NON PRESSURIZED — IDENTIFICATION NUMBER 231

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	1890.	218.076	529.100	1132.082
NU	EXPONENTIAL	17467.	29.294	57.252	105.258

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	3780	
NU	1	3	52400	

TANK		/ PRESSURIZED			IDENTIFICATION NUMBER 232
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	125000.	1.785	8.000	23.958
ML	EXPONENTIAL	*********	0.0	0.000	18084.918
NU	EXPONENTIAL	14837.	34.487	67.401	123.918

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	1	125000	
ML	1	0	89	
NU	2	3	44510	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.68

TELESCOPE / BORESIGHT — IDENTIFICATION NUMBER 233

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GM	EXPONENTIAL	30038.	20.568	33.292	52.843

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	2	5	150188	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.99

TELESCOPE / GENERAL — IDENTIFICATION NUMBER 234

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	*********	0.0	0.000	32.899

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	0	48924	

TERMINAL BOARDS / GENERAL — IDENTIFICATION NUMBER 235

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	195696.	2.934	5.110	8.587
GF	EXPONENTIAL	260072.	2.746	3.845	5.349
GM	EXPONENTIAL	492827.	1.595	2.029	2.579
NS	EXPONENTIAL	1011841.	0.812	0.988	1.203
NSB	EXPONENTIAL	131760.	4.689	7.590	12.001
NU	EXPONENTIAL	99560.	2.241	10.044	30.080

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	4	782784	
GF	5	9	2340646	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.35
GM	3	16	7885228	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.13
NS	3	23	23272336	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.17
NSB	3	5	658800	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.48
NU	1	1	99560	

THERMOCOUPLE		/ GENERAL		IDENTIFICATION NUMBER 236	
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	750000.	0.550	1.333	2.853
GM	EXPONENTIAL	75342.	9.989	13.273	17.584
NS	EXPONENTIAL	16903.	30.270	59.160	108.765

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	2	1500000	
GM	2	12	904089	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.78
NS	2	3	50710	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.52

TRACK BALL	/ ELECTROMECHANICAL				IDENTIFICATION NUMBER 237
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	24383.	34.823	41.012	48.329
GM	EXPONENTIAL	30794.	20.063	32.474	51.350
NS	EXPONENTIAL	128100.	6.350	7.806	9.597

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	2	32	780257	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.70
GM	3	5	153968	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.88
NS	2	21	2690101	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.17

TRANSMISSION / GENERAL			IDENTIFICATION NUMBER 238		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	907.	1044.302	1101.965	1163.125

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	262	237757	

TRUNNION ASSEMBLY / GENERAL			IDENTIFICATION NUMBER 239		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ARW	EXPONENTIAL	518.	1704.926	1930.854	2188.241

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ARW	1	53	27449	

VALVE	/ CONTROL-MANUAL		IDENTIFICATION NUMBER 240		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	91970.	8.183	10.873	14.405

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	12	1103639	

VALVE	/ GAS (AIR-VENT)		IDENTIFICATION NUMBER 241		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	894630.	0.461	1.118	2.392

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	2	1789259	

VALVE / HYDRAULIC — IDENTIFICATION NUMBER 242

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	*********	0.0	0.000	32.899
GF	EXPONENTIAL	166667.	3.904	6.000	9.076
GM	EXPONENTIAL	51001.	12.757	19.608	29.659
NS	EXPONENTIAL	31690.	18.118	31.556	53.027
NSB	EXPONENTIAL	4356.	163.977	229.592	319.379
NU	EXPONENTIAL	23100.	17.843	43.290	92.625

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	0	48924	
GF	1	6	1000000	
GM	2	6	306003	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.15
NS	2	4	126760	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.44
NSB	2	9	39200	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.92
NU	2	2	46200	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.85

VALVE	/ PNEUMATIC		IDENTIFICATION NUMBER 243		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	48924.	13.298	20.440	30.918
GF	EXPONENTIAL	250000.	1.649	4.000	8.559
GM	EXPONENTIAL	60471.	8.461	16.537	30.403
NS	EXPONENTIAL	*********	0.0	0.000	1.118
NU	EXPONENTIAL	21690.	10.289	46.104	138.070

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	6	293544	
GF	1	2	500000	
GM	1	3	181414	
NS	1	0	1440000	
NU	1	1	21690	

VALVE / SOLENOID OPERATED						IDENTIFICATION NUMBER 244

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	90000.	2.480	11.111	33.275

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	1	90000	

VALVE (ISOLATION) / PYROTECHNICALLY ACTUATED VALVE						IDENTIFICATION NUMBER 245

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ML	EXPONENTIAL	*********	SEE NOTE BELOW		

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ML	1	0	124	

NOTE: Low total part operating hours, develop failure data with caution

VALVE (RELIEF) / PRESSURE ACTUATED — IDENTIFICATION NUMBER 246

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ML	EXPONENTIAL	**********	SEE NOTE BELOW		

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ML	1	0	42	

VALVE (FILL & DRAIN) / HAND OPERATED PLUG VALVE — IDENTIFICATION NUMBER 247

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ML	EXPONENTIAL	**********	0.0	0.000	922.383

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ML	1	0	1745	

NOTE: Low total part operating hours, develop failure data with caution

VALVE(BIPROPELLANT-HIGH THURST/ SOLENOID OPERATED — IDENTIFICATION NUMBER 248

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ML	EXPONENTIAL	**********	SEE NOTE BELOW		

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ML	1	0	45	

VALVE(BIPROPELLANT-LOW THURST)/ TORQUE MOTOR OPERATED — IDENTIFICATION NUMBER 249

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
ML	EXPONENTIAL	**********	0.0	0.000	5152.230

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
ML	1	0	312	

NOTE: Low total part operating hours, develop failure data with caution

WASHER / FLAT			IDENTIFICATION NUMBER 250		
			FAILURE RATE (FAILURES PER MILLION HOURS)		
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	14567.	65.568	68.647	71.886
GF	EXPONENTIAL	1629170.	0.493	0.614	0.763
GM	EXPONENTIAL	6051034.	0.152	0.165	0.180
NS	EXPONENTIAL	2345333.	0.343	0.426	0.530
NSB	EXPONENTIAL	*********	0.0	0.000	2.454
NU	EXPONENTIAL	2742413.	0.225	0.365	0.577

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	356	5185944	
GF	3	19	30954240	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.27
GM	2	110	665613824	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.96
NS	1	19	44561328	
NSB	2	0	656000	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 1.00
NU	2	5	13712066	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.25

WASHER / LOCK — IDENTIFICATION NUMBER 251

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
AUT	EXPONENTIAL	11605.	81.188	86.168	91.483
GF	EXPONENTIAL	1706841.	0.447	0.586	0.767
GM	EXPONENTIAL	8636816.	0.097	0.116	0.138
NS	EXPONENTIAL	1161859.	0.711	0.861	1.043
NSB	EXPONENTIAL	*********	0.0	0.000	7.186
NU	EXPONENTIAL	834536.	0.688	1.198	2.014

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
AUT	1	215	2495124	
GF	3	13	22188944	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.77
GM	2	28	241830848	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.97
NS	2	24	27884624	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.84
NSB	1	0	224000	
NU	1	4	3338142	

WASHER / SHERR					IDENTIFICATION NUMBER 252
ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	637260.	0.350	1.569	4.699

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	1	637260	

WASHER / SPRING — IDENTIFICATION NUMBER 253

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	615994.	0.669	1.623	3.473
GM	EXPONENTIAL	232437.	3.381	4.302	5.469
NS	EXPONENTIAL	41920.	15.520	23.855	36.084
NU	EXPONENTIAL	**********	0.0	0.000	25.597

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	3	2	1231994	SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.16
GM	1	16	3718986	
NS	1	6	251520	
NU	1	0	62880	

WASHER / STAR — IDENTIFICATION NUMBER 254

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
GF	EXPONENTIAL	56624992.	0.010	0.018	0.030

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	4	226500000	

WATER DEMINERALIZER / MIX-RESIN — IDENTIFICATION NUMBER 255

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	13100.	17.035	76.336	228.807

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	1	13100	

WINDLASS / FROM ANCHOR — IDENTIFICATION NUMBER 258

ENV	DIST. TYPE	MEAN ESTIMATE (HOURS)	FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND	FAILURE RATE ESTIMATE	80% UPPER BOUND
NS	EXPONENTIAL	SEE NOTE BELOW			

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
NS	1	1	83	

NOTE: Low total part operating hours, develop failure data with ceution

5.3 Weibull Analyses -- Project 1. This section contains the results of fitting the Weibull distribution to nonelectronic part lifetime data collected on a ground mobile mortar locating radar. For each part type and class represented, a table is presented which gives the part identification number, a point estimate of mean life in hours, a point and 60% confidence interval estimate of the Weibull scale parameter in hours, and a point and 60% confidence interval estimate of the Weibull shape parameter. The form of the Weibull survival function considered here is given by:

$$\Pr(\text{survive } t) = \exp[-(t/b)^c],$$

where $b>0$ is the scale parameter, $c>0$ is the shape parameter, and $t>0$ is measured in hours. This convention is followed throughout sections 5.3 - 5.5.

In addition to these quantities, the total part operating hours are given, along with the total number of failures. The "comments" field contains the predominant failure mode observed (i.e. the failure mode which occurred most often in the sample) and the observed significance level for testing exponentiality. We recommend that exponentiality be rejected if the observed significance level is below 0.05, although other thresholds may be used according to the particular application.

In some cases, less than two failures are reported. However, because there are multiple systems reporting (53 in this case) and one or more parts per system, the systems which have no failures were also used as "data" so that the two parameters of interest could actually be estimated. This applies to section 5.4 also.

In only one instance in project 1 is exponentiality rejected at the 0.05 significance level, namely for electrostatic high speed printers (identification number 1-2-36). The Weibull shape parameter estimate in this case was 0.748. The corresponding Weibull distribution would, in this case, have a decreasing failure rate and its probability density function would be shaped somewhat like that of the exponential distribution. One interpretation for the shape parameter being less than one is that infant failures were still taking place in the printers after they were installed. If this is true, it would be indicative of poor vendor quality control.

5.3.1 Weibull Analyses Summaries. Following is an index of the nonelectronic parts analyzed in this section. Each part is identified by a number of the form "x-y-z". The prefix "x" identifies the project from which the data was collected ("x" is 1 in this section). The number "y", being either 1,2, or 3 indicates the sampling and censoring scheme (in the statistical sense) used in collection the data for that part. These schemes are described in the Final Technical Report of this study. The number "z" is the sequence number as listed in the index that follows.

The column under "Best Fit" indicates which distribution is the better fitting distribution (assuming 0.05 significance level) with E=exponential, and W=Weibull. The format for this index is used in sections 5.4 and 5.5. also.

Index to Project 1 Weibull Analyses

Part Name	Part Type	Environment	Sequence Number	Best Fit
ACCELEROMETER	FORCED BALANCE	GM	1	E
ACTUATOR	LINEAR	GM	2	E
AXLE	GENERAL	GM	3	E
AZIMUTH ENCODER	OPTICAL	GM	4	E
BATTERY	RECHARGEABLE	GM	5	E
BEARING	BALL	GM	6	E
BEARING	ROLLER	GM	7	E
BEARING	SLEEVE		8	E
BELLOWS	GENERAL	GM	9	E
BELT	TIMING	GM	10	E
BLOWERS & FANS	AXIAL	GM	11	E
BRAKES	ELECTROMECHANICAL	GM	12	E
BRUSHES	ELECTRICAL MOTOR	GM	13	E
CIRCUIT PROTECTION DEVICE	SPARK GAP	GM	14	E
CIRCUIT PROTECTION DEVICE	SURGE ARRESTER	GM	15	E
CLUTCH	FRICTION	GM	16	E
COMPUTER MASS MEMORY	MAGNETIC TAPE	GM	17	E
COUPLING	FLEXIBLE	GM	18	E
COUPLING	RIGID	GM	19	E
CRANK SHAFT	GENERAL	GM	20	E
DRIVE FOR COMPUTER TAPES/DISCS	MAGNETIC TAPE DRIVE	GM	21	E
DRIVES	GEAR	GM	22	E
DRIVES	VARIABLE PITCH	GM	23	E
DRUM	WEAPON LOCATION UNIT	GM	24	E
DUCT	GENERAL	GM	25	E
ELECTRIC HEATERS	RESISTANCE	GM	26	E
FILTERS	AIR (GAS)	GM	27	E
FITTINGS	PERMANENT	GM	28	E
GASKETS & SEALS	DYNAMIC	GM	29	E
GEAR	STATIC	GM	30	E
GEAR	BEVEL	GM	31	E
GEAR	HELICAL	GM	32	E
GEAR	SPUR	GM	33	E
GEAR BOX	REDUCTION	GM	34	E
HEAT EXCHANGERS	COPLATES	GM	35	E
HIGH SPEED PRINTERS	ELECTROSTATIC	GM	36	W
HOSES	GENERAL	GM	37	E
INSTRUMENTS	AMMETER	GM	38	E
INSTRUMENTS	VOLTMETER	GM	39	E
JOINT, MICROWAVE ROTARY	GENERAL	GM	40	E
KEYBOARD	ELECTROMECHANICAL	GM	41	E
MOTOR, ELECTRIC	SERVO, DC	GM	42	E
MOTOR, ELECTRIC	STEPPER	GM	43	E
POWER SWITCH GEAR		GM	44	E
PULLEY	GROOVED	GM	45	E

Index to Project 1 Weibull Analyses

Part Name	Part Type	Environment	Sequence Number	Best Fit
RETAINING RING	GENERAL	GM	46	E
SHAFT	GENERAL	GM	47	E
SOLENOIDS	LINEAR	GM	48	E
SWITCH	PRESSURE (AIR FLOW)	GM	49	E
SWITCH	THERMOSTATIC	GM	50	E
VALVES	PENUMATIC	GM	51	E

ACCELEROMETER / FORCED BALANCED						IDENTIFICATION NUMBER 1-1- 1		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	65890.17	0.0	62580.41	131290.35	0.623	0.899	1.175

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	4	181414.	DEFECTIVE PARTS INSIDE SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.762

ACTUATOR / LINEAR						IDENTIFICATION NUMBER 1-2- 2		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	7518.42	5018.08	7361.84	9705.60	0.790	0.954	1.118

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	13	90707.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =[illegible]

AXLE / GENERAL						IDENTIFICATION NUMBER 1-1- 3		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	26360.24	795.80	29306.49	57817.18	0.842	1.549	2.256

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	90707.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.487

AZIMUTH ENCODER / OPTICAL						IDENTIFICATION NUMBER 1-2- 4		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	3898.20	3430.82	4158.22	4885.62	1.054	1.216	1.378

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	19	90707.	ANTENNA WON'T MOVE SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.244

BATTERY	/ RECHARGEABLE					IDENTIFICATION NUMBER 1-1- 5		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	130716.62	0.0	129683.31	310343.12	0.650	0.982	1.314

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	362828.	CONNECTOR PINS SHORTED SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.963

BEARING	/ BALL					IDENTIFICATION NUMBER 1-1- 6		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	113304.26	15188.33	117898.94	220799.55	0.865	1.117	1.368

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	6	1088484.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.692

BEARING / ROLLER — IDENTIFICATION NUMBER 1-1- 7

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	279610.93	0.0	254716.67	716746.73	0.531	0.838	1.145

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	362828.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.668

BEARING / SLEEVE — IDENTIFICATION NUMBER 1-1- 8

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	124555.02	0.0	130751.50	269865.58	0.836	1.146	1.457

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	4	907070.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.687

BELLOWS / GENERAL						IDENTIFICATION NUMBER 1-1- 9		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	10734.21	7589.02	11989.22	16389.42	1.668	3.176	4.683

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	90707.	CRACKED SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.103

BELT / TIMING						IDENTIFICATION NUMBER 1-1-10		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	20305.47	9855.58	22817.05	35778.51	1.210	1.773	2.338

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	181414.	WORN OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.208

BLOWERS & FANS	/ AXIAL					IDENTIFICATION NUMBER 1-3-11		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	221726.04	0.0	187582.37	398396.87	0.580	0.757	0.933

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	8	516594.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.271

BRAKES	/ ELECTROMECHANICAL					IDENTIFICATION NUMBER 1-2-12		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	3367.52	2911.59	3507.71	4103.83	0.979	1.117	1.255

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	24	90707.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.465

BRUSHES / ELECTRICAL MOTOR — IDENTIFICATION NUMBER 1-1-13

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	68275.17	0.0	73790.65	158845.39	0.829	1.289	1.748

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	362828.	SHORTED SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.585

CIRCUIT PROTECTION DEVICE / SPARK GAP — IDENTIFICATION NUMBER 1-1-14

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	64458.65	0.0	66765.81	190449.44	0.494	1.098	1.702

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	90707.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.890

CIRCUIT PROTECTION DEVICE / SURGE ARRESTER — IDENTIFICATION NUMBER 1-1-15

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	31693.39	7753.35	33976.80	60200.25	0.875	1.242	1.609

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	181414.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.569

CLUTCH / FRICTION — IDENTIFICATION NUMBER 1-2-16

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	10397.23	6485.69	11087.16	15688.62	0.941	1.215	1.489

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	6	90707.	ANTENNA FAILS TO ROTATE SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.497

COMPUTER MASS MEMORY / MAGNETIC TAPE — IDENTIFICATION NUMBER 1-2-17

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	3254.01	2330.26	2876.68	3423.10	0.716	0.802	0.888

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	35	90707.	WON'T LOAD SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.064

COUPLING / FLEXIBLE — IDENTIFICATION NUMBER 1-1-18

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	51383.91	0.0	56492.70	133424.34	0.740	1.419	2.097

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	181414.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.587

COUPLING	/ RIGID					IDENTIFICATION NUMBER 1-1-19		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	1079237.26	0.0	1066291.17	4931904.61	0.398	0.973	1.547

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	907070.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.968

CRANK SHAFT	/ GENERAL					IDENTIFICATION NUMBER 1-1-20		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	31668.10	0.0	33113.46	67287.92	0.698	1.131	1.564

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	90707.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.795

DRIVE FOR COMPUTER TAPES/DISCS/ MAGNETIC TAPE DRIVE — IDENTIFICATION NUMBER 1-2-21

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	2691.13	2187.81	2598.07	3008.34	0.834	0.927	1.020

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	36	90707.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.515

DRIVES / GEAR — IDENTIFICATION NUMBER 1-1-22

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	54124.41	5467.83	58133.14	110798.45	0.882	1.252	1.622

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	362828.	IMPROPER ADJUSTMENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.556

DRIVES / VARIABLE PITCH — IDENTIFICATION NUMBER 1-1-23

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	19581.54	8588.69	21489.09	36389.48	0.932	1.402	1.872

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	90707.	IMPROPER ADJUSTMENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.454

DRUM / WEAPON LOCATION UNIT — IDENTIFICATION NUMBER 1-2-24

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	4664.01	3683.43	4707.49	5731.54	0.882	1.023	1.164

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	19	91088.	DRUM STICKS SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.891

DUCT		/ GENERAL				IDENTIFICATION NUMBER 1-1-25		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	454731.46	0.0	437147.91	1072003.25	0.670	0.920	1.169

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	5	1451312.	USED UP.NEEDS REPLACEMENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.789

ELECTRIC HEATERS		/ RESISTANCE				IDENTIFICATION NUMBER 1-1-26		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	33384.04	6986.72	35612.00	64237.29	0.852	1.216	1.581

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	181414.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.609

FILTERS / AIR (GAS) — IDENTIFICATION NUMBER 1-3-27

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	238600.87	0.0	240544.09	693739.61	0.609	1.020	1.430

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	525672.	NEEDS REPLACEMENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.987

FITTINGS / PERMANENT — IDENTIFICATION NUMBER 1-1-28

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	89359.57	0.0	97964.93	257768.71	0.717	1.393	2.069

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	362828.	IMPROPER ADJUSTMENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.609

GASKETS & SEALS / DYNAMIC — IDENTIFICATION NUMBER 1-1-29

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	175631.12	0.0	183181.28	429526.25	0.768	1.122	1.476

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	907070.	NEEDS REPLACEMENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.768

GASKETS & SEALS / STATIC — IDENTIFICATION NUMBER 1-1-30

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	83986.29	2554.53	87783.85	173013.17	0.823	1.130	1.437

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	4	544242.	NEEDS REPLACEMENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.717

GEAR / BEVEL						IDENTIFICATION NUMBER 1-1-31		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	118856.11	0.0	126548.84	305564.45	0.760	1.207	1.654

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	544242.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.689

GEAR / HELICAL						IDENTIFICATION NUMBER 1-1-32		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	35476.88	0.0	38672.51	87971.17	0.687	1.347	2.007

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	90707.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.646

GEAR / SPUR — IDENTIFICATION NUMBER 1-1-33

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	55819.02	4712.54	59815.99	114919.43	0.871	1.240	1.608

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	362828.	WORN OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.574

GEAR BOX / REDUCTION — IDENTIFICATION NUMBER 1-1-34

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	34678.72	0.0	37860.85	85458.13	0.696	1.359	2.022

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	90707.	NEEDS OVERHAUL SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.636

HEAT EXCHANGERS / COPLATES						IDENTIFICATION NUMBER 1-1-35		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	40579.80	8321.07	43790.21	79259.35	0.906	1.279	1.652

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	272121.	NEEDS ADJUSTMENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.518

HIGH SPEED PRINTERS / ELECTROSTATIC						IDENTIFICATION NUMBER 1-2-38		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	1732.16	1279.95	1486.24	1692.53	0.706	0.770	0.835

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	64	90707.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.005

HOSES		/ GENERAL				IDENTIFICATION NUMBER 1-1-37		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	34968.20	0.0	38164.63	86043.48	0.695	1.356	2.018

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	90707.	WORN OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.637

INSTRUMENTS		/ AMMETER				IDENTIFICATION NUMBER 1-1-38		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	55723.50	0.0	58510.81	159288.74	0.530	1.147	1.765

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	90707.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.838

INSTRUMENTS / VOLTMETER						IDENTIFICATION NUMBER 1-1-39		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	49694.65	0.0	52728.06	112377.31	0.749	1.191	1.634

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	181414.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.710

JOINT,MICROWAVE ROTARY / GENERAL						IDENTIFICATION NUMBER 1-1-40		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	53027.44	2131.45	55938.90	109746.35	0.808	1.166	1.524

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	272121.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.691

KEYBOARD / ELECTROMECHANICAL — IDENTIFICATION NUMBER 1-2-41

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	10215.75	5395.26	8841.30	12287.33	0.647	0.779	0.911

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	14	90707.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.180

MOTOR,ELECTRIC / SERVO,DC — IDENTIFICATION NUMBER 1-1-42

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	97451.22	0.0	87189.28	244094.99	0.448	0.816	1.184

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	90707.	WLU MAP DRUM OSCILLATES,DEMAGNETIZED SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.885

MOTOR, ELECTRIC / STEPPER						IDENTIFICATION NUMBER 1-1-43		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	36136.15	0.0	39353.01	89861.35	0.680	1.340	2.000

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	90707.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.652

POWER SWITCH GEAR /						IDENTIFICATION NUMBER 1-1-44		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	47998.39	0.0	52967.52	121520.84	0.769	1.456	2.143

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	181414.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.557

PULLEY / GROOVED — IDENTIFICATION NUMBER 1-1-45

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	50940.81	0.0	53924.21	116745.09	0.735	1.181	1.627

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	181414.	PRINTER INOPERATIVE SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.727

RETAINING RING / GENERAL — IDENTIFICATION NUMBER 1-3-46

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	229156.66	14887.05	237905.12	460923.18	0.878	1.106	1.334

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	7	2652030.	NEEDS REPLACEMENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.692

SHAFT / GENERAL — IDENTIFICATION NUMBER 1-3-47

ENV	DIST. TYPE	MEAN ESTIMATE	SCALE 80% LOWER BOUND	SCALE POINT ESTIMATE	SCALE 80% UPPER BOUND	SHAPE 80% LOWER BOUND	SHAPE POINT ESTIMATE	SHAPE 80% UPPER BOUND
GM	WEIBULL	92956.61	11801.65	86557.76	161313.87	0.678	0.868	1.058

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	8	434030.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.570

SOLENOIDS / LINEAR — IDENTIFICATION NUMBER 1-1-48

ENV	DIST. TYPE	MEAN ESTIMATE	SCALE 80% LOWER BOUND	SCALE POINT ESTIMATE	SCALE 80% UPPER BOUND	SHAPE 80% LOWER BOUND	SHAPE POINT ESTIMATE	SHAPE 80% UPPER BOUND
GM	WEIBULL	83937.45	0.0	84638.07	210877.66	0.607	1.020	1.434

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	181414.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.987

SWITCH		/ PRESSURE (AIR FLOW)				IDENTIFICATION NUMBER 1-1-49		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	47632.70	16600.12	50014.64	83429.15	0.896	1.147	1.399

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	6	453535.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.616

SWITCH		/ THERMOSTATIC				IDENTIFICATION NUMBER 1-3-50		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	65219.07	23705.78	67732.24	111758.70	0.910	1.107	1.304

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	12	1179360.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.841

VALVES		/ PNEUMATIC				IDENTIFICATION NUMBER 1-1-51		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	27337.24	9207.89	29694.76	50181.[illegible]4	0.943	1.321	1.700

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	181414.	SEAL WORN OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.459

5.4 Weibull Analyses -- Project 2. This section contains the results of fitting the Weibull distribution to nonelectronic part lifetime data collected from a ground mobile artillery locating radar. For a description of the tables in this section, refer to section 5.3.

In only three cases is exponentiality rejected at the 0.05 level of significance. These cases are listed below.

Part Class	Type	Shape Parameter Estimate
Accelerometer	Forced Balanced	0.297
Azimuth Encoder	Optical	0.641
Crank Shaft	General	0.413

Note that in each of these cases, the corresponding Weibull distribution has a decreasing failure rate. This is perhaps indicative of the occurrence of infant failures which were not properly screened by the vendor, or, as with the Accelerometer nd Crank Shaft, a very small sample of failures.

5.4.1 Weibull Analyses Summaries. Following is an index of the nonelectronic parts analyzed in this section. See section 5.3.1 for a description of the entries of this index.

Index to Project 2 Weibull Analyses

Part Name	Part Type	Environment	Sequence Number	Best Fit
ACCELEROMETER	FORCED BALANCED	GM	1	W
ACTUATOR	MECHANICAL	GM	2	E
ANTENNA	COMMUNICATION	GM	3	E
AXLE	GENERAL	GM	4	E
AZIMUTH ENCODER	OPTICAL	GM	5	W
BATTERY	RECHARGEABLE	GM	6	E
BEARING	BALL	GM	7	E
BEARING	ROLLER	GM	8	E
BEARING	SLEEVE	GM	9	E
BELLOWS	GENERAL	GM	10	E
BELT	TIMING	GM	11	E
BELT	V-BELT	GM	12	E
BLOWERS & FANS	AXIAL	GM	13	E
BLOWERS & FANS	CENTRIFUGAL	GM	14	E
BRAKES	ELECTROMECHANICAL	GM	15	E
BRUSHES	ELECTRIC MOTOR	GM	16	E
BUSHINGS	GENERAL	GM	17	E
CIRCUIT PROTECTION DEVICE	SPARK GAP	GM	18	E
CIRCUIT PROTECTION DEVICE	SURGE ARRESTER	GM	19	E
CLUTCH	FRICTION	GM	20	E
COMPUTER MASS MEMORY	MAGNETIC TAPE	GM	21	E
CRANK SHAFT	GENERAL	GM	22	W
DIAPHRAGMS BURST	GENERAL	GM	23	E
DRIVE FOR COMPUTER TAPES/DISCS	MAGNETIC TAPE TRANS.	GM	24	E
DRIVES	GEAR	GM	25	E
DRIVES	VARIABLE PITCH	GM	26	E
DRUM	WEAPON LOCATING UNIT	GM	27	E
DUCT	GENERAL	GM	28	E
ELECTRIC HEATERS	RESISTANCE	GM	29	E
ELECTROMECHANICAL TIMERS	GENERAL	GM	30	E
FILTERS	AIR	GM	31	E
FILTERS	LIQUID	GM	32	E
FITTINGS	PERMANENT	GM	33	E
FITTINGS	QUICK DISCONNECT	GM	34	E
FITTINGS	THREADED	GM	35	E
FUSE HOLDER	BLOCK	GM	36	E
FUSE HOLDER	PLUG	GM	37	E
GASKETS & SEALS	DYNAMIC	GM	38	E
GASKETS & SEALS	STATIC	GM	39	E
GEAR	BEVEL	GM	40	E
GEAR	HELICAL	GM	41	E
GEAR	SPUR	GM	42	E
GEAR BOX	REDUCTION	GM	43	E
HEAT EXCHANGERS	RADIATOR	GM	44	E
HIGH SPEED PRINTERS	ELECTROSTATIC	GM	45	E
HOSES	GENERAL	GM	46	E

Index to Project 2 Weibull Analyses

Part Name	Part Type	Environment	Sequence Number	Best Fit
INSTRUMENTS	AMMETER	GM	47	E
INSTRUMENTS	VOLTMETER	GM	48	E
JOINT, MICROWAVE ROTARY	GENERAL	GM	49	E
KEYBOARD	ELECTROMECHANICAL	GM	50	E
METAL TUBING	GENERAL	GM	51	E
MOTOR, ELECTRIC	> 1 HORSE POWER, AC	GM	52	E
MOTOR, ELECTRIC	SERVO, DC	GM	53	E
MOTOR, ELECTRIC	STEPPER	GM	54	E
POWER CIRCUIT BREAKER	CURRENT TRIP	GM	55	E
PULLEY	GROOVED	GM	56	E
PULLEY	V-PULLEY	GM	57	E
PUMP	HYDRAULIC	GM	58	E
PUMP	PNEUMATIC	GM	59	E
RESILIENT MOUNT	GENERAL	GM	60	E
RETAINING RING	GENERAL	GM	61	E
SHOCK ABSORBERS	COMBINATION	GM	62	E
SHOCK ABSORBERS	RESILIENT	GM	63	E
SWITCH	LIQUID FLOW	GM	64	E
SWITCH	PRESSURE (AIR FLOW)	GM	65	E
SWITCH	THERMOSTATIC	GM	66	E
SWITCH	WAVE GUIDE	GM	67	E
TELESCOPE	BORE SIGHT	GM	68	E
TRACK BALL	ELECTROMECHANICAL	GM	69	E
VALVES	HYDRAULIC	GM	70	E

ACCELEROMETER		/ FORCED BALANCED				IDENTIFICATION NUMBER 2-3- 1		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	***********	0.0	21611482.92	***********	0.160	0.297	0.433

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	112682.	DEFECTIVE PARTS INSIDE SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.003

ACTUATOR		/ MECHANICAL				IDENTIFICATION NUMBER 2-1- 2		
ENV	DIST TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	17576.23	4960.86	18972.54	32984.22	0.784	1.281	1.778

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	59481.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.620

ANTENNA / COMMUNICATION						IDENTIFICATION NUMBER 2-1- 3		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	1400759.62	0.0	993079.80	5427732.47	0.178	0.632	1.086

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	118962.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.543

AXLE / GENERAL						IDENTIFICATION NUMBER 2-1- 4		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	58898.86	0.0	62992.93	168271.36	0.530	1.229	1.929

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	118962.	DAMAGED SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.775

AZIMUTH ENCODER / OPTICAL — IDENTIFICATION NUMBER 2-2- 5

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	10502.73	4023.89	7571.59	11119.30	0.513	0.641	0.770

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	12	59481.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.034

BATTERY / RECHARGEABLE — IDENTIFICATION NUMBER 2-1- 6

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	1433685.15	0.0	1012499.16	4224447.36	0.310	0.630	0.951

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	237924.	SHORTED VR1-3 TO CHASSIS SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.387

BEARING / BALL						IDENTIFICATION NUMBER 2-1- 7		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	98318.52	8451.73	97196.10	185940.48	0.726	0.974	1.222

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	6	535329.	EXCESSIVE PLAY SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.930

BEARING / ROLLER						IDENTIFICATION NUMBER 2-1- 8		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	133721.94	0.0	132010.90	357064.22	0.543	0.971	1.399

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	237924.	LUBRICATION DRIED OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.955

BEARING / SLEEVE						IDENTIFICATION NUMBER 2-1- 9		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	437249.87	0.0	402329.97	1172904.55	0.529	0.851	1.174

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	594810.	REQUIRES OVERHAUL SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.709

BELLOWS / GENERAL						IDENTIFICATION NUMBER 2-1-10		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	262866.38	0.0	207917.25	879943.96	0.214	0.701	1.188

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	59481.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.635

BELT	/ TIMING					IDENTIFICATION NUMBER 2-1-11		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	56859.35	0.0	60995.18	160377.56	0.542	1.245	1.949

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	118962.	WORN OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.760

BELT	/ V-BELT					IDENTIFICATION NUMBER 2-1-12		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	29334.21	0.0	31777.46	71473.99	0.586	1.303	2.021

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	59481.	BROKEN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.709

BLOWERS & FANS		/ AXIAL				IDENTIFICATION NUMBER 2-3-13		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	289726.63	0.0	247070.90	597030.43	0.541	0.784	0.987

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	6	509460.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.409

BLOWERS & FANS		/ CENTRIFUGAL				IDENTIFICATION NUMBER 2-1-14		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	570851.43	0.0	491516.46	1519208.55	0.471	0.774	1.076

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	475848.	BEARINGS WORN OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.554

BRAKES / ELECTROMECHANICAL						IDENTIFICATION NUMBER 2-3-15		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	21667.34	7828.78	17422.70	27016.62	0.563	0.713	0.884

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	10	105056.	EXCESSIVE GAP SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.137

BRUSHES / ELECTRIC MOTOR						IDENTIFICATION NUMBER 2-1-16		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	795505.51	0.0	700628.90	3354568.10	0.263	0.798	1.333

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	237924.	NEEDS ADJUSTMENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.763

BUSHINGS / GENERAL						IDENTIFICATION NUMBER 2-1-17		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	207816.85	40062.94	231388.30	422713.67	1.234	1.571	1.908

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	6	13026339.	WORN OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.118

CIRCUIT PROTECTION DEVICE / SPARK GAP						IDENTIFICATION NUMBER 2-1-18		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	124668.75	0.0	111922.87	400619.42	0.279	0.820	1.360

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	59481.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.789

CIRCUIT PROTECTION DEVICE / SURGE ARRESTER — IDENTIFICATION NUMBER 2-1-19

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	1347662.81	0.0	886354.76	3701416.46	0.289	0.595	0.902

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	178443.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.330

CLUTCH / FRICTION — IDENTIFICATION NUMBER 2-1-20

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	119774.67	0.0	108271.87	304747.72	0.441	0.828	1.216

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	118962.	ANTENNA FAILS TO ROTATE SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.721

COMPUTER MASS MEMORY / MAGNETIC TAPE						IDENTIFICATION NUMBER 2-1-21		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	29420.65	1812.84	24868.76	47924.68	0.505	0.756	1.007

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	4	59481.	WON'T LOAD SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.443

CRANK SHAFT / GENERAL						IDENTIFICATION NUMBER 2-2-22		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	1013766.24	0.0	331808.41	1175986.58	0.231	0.413	0.595

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	59481.	BRACKET BROKEN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.037

DIAPHRAGMS BURST / GENERAL								IDENTIFICATION NUMBER 2-1-23
ENV	DIST TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
	WEIBULL	409183.72	0.0	298265.16	1376933.67	0.186	0.648	1.109

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	59481	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.564

IVE FOR COMPUTER TAPES/DISCS/ MAGNETIC TAPE TRANSPORT								IDENTIFICATION NUMBER 2-1-24
ENV	DIST TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	1262797.98	0.0	517993.27	2197885.61	0.209	0.453	0.698

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	59481	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.133

DRIVES / GEAR						IDENTIFICATION NUMBER 2-1-25		
ENV	DIST TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	112079.01	0.0	112796.38	260004.45	0.655	1.016	1.376

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	356886.	NEEDS REPLACEMENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.971

DRIVES / VARIABLE PITCH						IDENTIFICATION NUMBER 2-1-26		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	16828.00	5613.63	18281.23	30948.82	0.815	1.322	1.830

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	59481.	WORN OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.573

DRUM / WEAPON LOCATING UNIT — IDENTIFICATION NUMBER 2-1-27

ENV	DIST TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	15290.09	4908.24	15199.73	25491.22	0.663	0.986	1.310

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	4	59481.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.972

DUCT / GENERAL — IDENTIFICATION NUMBER 2-1-28

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	320770.11	0.0	301519.04	715859.70	0.627	0.882	1.138

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	5	892215.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.707

ELECTRIC HEATERS / RESISTANCE — IDENTIFICATION NUMBER 2-1-29

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	21004.97	8111.19	23371.17	38631.14	0.992	1.561	2.129

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	118962.	SHORTED SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.367

ELECTROMECHANICAL TIMERS / GENERAL — IDENTIFICATION NUMBER 2-1-30

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	19663.70	7630.35	21453.53	35276.70	0.906	1.'53	1.801

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	118962.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.480

FILTERS / AIR — IDENTIFICATION NUMBER 2-1-31

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	20949.63	3472.11	20728.06	37984.01	0.625	0.976	1.327

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	59481.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.954

FILTERS / LIQUID — IDENTIFICATION NUMBER 2-1-32

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	37650.97	19720.18	40196.86	60673.54	0.975	1.220	1.466

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	8	535329.	LEAKING SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.433

FITTINGS / PERMANENT — IDENTIFICATION NUMBER 2-3-33

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	10254430.80	0.0	7302483.72	28354012.69	0.410	0.635	0.859

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	4	1723290.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.222

FITTINGS / QUICK DISCONNECT — IDENTIFICATION NUMBER 2-1-34

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	139991.19	0.0	129990.22	324602.92	0.540	0.864	1.188

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	237924.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.733

FITTINGS / THREADED — IDENTIFICATION NUMBER 2-1-35

ENV	DIST. TYPE	MEAN ESTIMATE	SCALE 80% LOWER BOUND	SCALE POINT ESTIMATE	SCALE 80% UPPER BOUND	SHAPE 80% LOWER BOUND	SHAPE POINT ESTIMATE	SHAPE 80% UPPER BOUND
GM	WEIBULL	339122.53	0.0	319992.17	815290.52	0.602	0.888	1.175

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	4	773253.	LEAKING SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.750

FUSE HOLDER / BLOCK — IDENTIFICATION NUMBER 2-1-36

ENV	DIST. TYPE	MEAN ESTIMATE	SCALE 80% LOWER BOUND	SCALE POINT ESTIMATE	SCALE 80% UPPER BOUND	SHAPE 80% LOWER BOUND	SHAPE POINT ESTIMATE	SHAPE 80% UPPER BOUND
GM	WEIBULL	707994.58	0.0	632133.96	2966092.95	0.271	0.813	1.356

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	237924.	DAMAGED SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.782

FUSE HOLDER / PLUG						IDENTIFICATION NUMBER 2-1-37		
ENV	DIST TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	5863776.40	0.0	11400990.36	81379544.47	0.181	0.640	1.099

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	594810.	DAMAGED SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.555

GASKETS & SEALS / DYNAMIC						IDENTIFICATION NUMBER 2-3-38		
ENV	DIST TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	2393608.94	0.0	1912170.23	8253465.48	0.359	0.708	1.057

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	594810.	LEAKING SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.518

GASKETS & SEALS		/ STATIC				IDENTIFICATION NUMBER 2-1-39		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	443979.34	0.0	424115.17	1038827.92	0.647	0.909	1.170

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	5	1368063.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.773

GEAR		/ BEVEL				IDENTIFICATION NUMBER 2-1-40		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	933130.85	0.0	852593.58	4100974.33	0.287	0.[illegible]42	1.397

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	356886.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.818

GEAR / HELICAL						IDENTIFICATION NUMBER 2-1-41		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	28725.94	0.0	31179.10	69486.06	0.594	1.316	2.038

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	59481.	WORN OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.698

GEAR / SPUR						IDENTIFICATION NUMBER 2-1-42		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	305094.17	0.0	297975.62	916483.59	0.526	0.949	1.372

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	475848.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.920

GEAR BOX / REDUCTION — IDENTIFICATION NUMBER 2-1-43

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	73061.95	0.0	71067.04	177693.41	0.521	0.941	1.361

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	118962.	NO OIL IN GEAR BOX SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.907

HEAT EXCHANGERS / RADIATOR — IDENTIFICATION NUMBER 2-1-44

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	968374.54	0.0	793508.09	3064689.05	0.373	0.728	1.084

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	356888.	NOT PROPERLY FABRICATED BY VENDOR SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.552

HIGH SPEED PRINTERS / ELECTROSTATIC — IDENTIFICATION NUMBER 2-2-45

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	5317.82	3667.88	5171.37	6674.85	0.770	0.941	1.111

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	12	59481.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.773

HOSES / GENERAL — IDENTIFICATION NUMBER 2-3-46

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	1697362.80	0.0	1610694.75	4540045.06	0.640	0.897	1.155

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	5	4299481.	HOSE HAS CRACKS DUE TO ANTENNA MOVEMENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.744

INSTRUMENTS / AMMETER						IDENTIFICATION NUMBER 2-1-47		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	122545.11	0.0	110322.28	393320.44	0.281	0.823	1.365

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	59481	SEALING DAMAGED SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.793

INSTRUMENTS / VOLTMETER						IDENTIFICATION NUMBER 2-1-48		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	2627205.96	0.0	1671884.11	9987333.85	0.156	0.581	1.006

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	118962	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.472

JOINT,MICROWAVE ROTARY / GENERAL						IDENTIFICATION NUMBER 2-1-49		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	270665.42	0.0	259247.87	794649.12	0.500	0.913	1.326

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	356886.	DEFECTIVE SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.862

KEYBOARD / ELECTROMECHANICAL						IDENTIFICATION NUMBER 2-2-50		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	23734.58	3456.68	19793.06	36129.44	0.510	0.744	0.977

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	5	59481.	LOCKED UP SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.393

METAL TUBING / GENERAL						IDENTIFICATION NUMBER 2-1-51		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	306441.73	0.0	321143.95	926619.51	0.665	1.140	1.614

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	1189620.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.799

MOTOR,ELECTRIC / > 1 HORSE POWER, AC						IDENTIFICATION NUMBER 2-1-52		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	371635.49	0.0	212811.17	764417.81	0.260	0.541	0.822

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	59481.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.244

MOTOR.ELECTRIC		/ SERVO.DC				IDENTIFICATION NUMBER 2-1-53		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	30337.19	0.0	30237.56	63713.84	0.565	0.992	1.420

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	59481.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.988

MOTOR.ELECTRIC		/ STEPPER				IDENTIFICATION NUMBER 2-1-54		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	72837.22	0.0	70850.67	219393.30	0.348	0.941	1.535

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	59481.	PAPER TAKE UP UNEVEN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.935

POWER CIRCUIT BREAKER / CURRENT TRIP						IDENTIFICATION NUMBER 2-3-55		
ENV	DIST TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	132440.51	12053.05	130601.23	249149.41	0.742	0.969	1.196

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	7	816970.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.909

PULLEY / GROOVED						IDENTIFICATION NUMBER 2-1-56		
ENV	DIST TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	34714.05	0.0	36986.36	89230.82	0.524	1.211	1.897

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	59481.	WORN OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.790

PULLEY / V-PULLEY — IDENTIFICATION NUMBER 2-1-57

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	89085.97	0.0	87826.09	198794.33	0.619	0.968	1.317

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	237924.	WORN OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.939

PUMP / HYDRAULIC — IDENTIFICATION NUMBER 2-1-58

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	7784.48	6591.90	8756.86	10921.83	1.376	1.814	2.252

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	4	59481.	CIRCUIT BREAKER TRIPS SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.080

PUMP / PNEUMATIC						IDENTIFICATION NUMBER 2-1-59		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	17897.50	5075.40	18249.51	31423.62	0.692	1.050	1.408

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	59481.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.905

RESILIENT MOUNT / GENERAL						IDENTIFICATION NUMBER 2-1-60		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	332403.25	0.0	325104.59	759332.85	0.683	0.952	1.220

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	5	1308582.	IMPROPER MOUNT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.881

RETAINING RING / GENERAL						IDENTIFICATION NUMBER 2-1-61		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	517555.16	0.0	536833.42	2156620.53	0.445	1.103	1.760

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	1	892215.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.893

SHOCK ABSORBERS / COMBINATION						IDENTIFICATION NUMBER 2-1-62		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	32380.29	6750.00	36039.38	65328.76	0.979	1.565	2.152

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	237924.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.376

SHOCK ABSORBERS / RESILIENT						IDENTIFICATION NUMBER 2-1-63		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	22550.79	7271.53	24970.42	42669.31	0.936	1.495	2.054

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	118962.	IMPROPER MOUNT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.421

SWITCH / LIQUID FLOW						IDENTIFICATION NUMBER 2-3-64		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	71833.38	0.0	75533.35	174174.56	0.677	1.153	1.628

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	237924.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.781

SWITCH	/ PRESSURE(AIR FLOW)					IDENTIFICATION NUMBER 2-1-65		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	699927.62	0.0	554124.50	1796714.96	0.419	0.702	0.985

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	356886	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.415

SWITCH	/ THERMOSTATIC					IDENTIFICATION NUMBER 2-3-66		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	468654.17	0.0	439528.39	1006599.28	0.664	0.879	1.094

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	8	1906536	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.647

SWITCH / WAVE GUIDE — IDENTIFICATION NUMBER 2-1-67

ENV	DIST TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	145020.37	0.0	87969.92	241296.36	0.327	0.562	0.796

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	3	59481.	IMPROPER WIRING SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.178

TELESCOPE / BORE SIGHT — IDENTIFICATION NUMBER 2-1-68

ENV	DIST TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	163948.91	0.0	115523.25	364350.35	0.311	0.629	0.946

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	59481.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.381

TRACK BALL		/ ELECTROMECHANICAL				IDENTIFICATION NUMBER 2-1-69		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	22514.64	2009.95	23506.14	45002.33	0.663	1.126	1.589

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	2	59481.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.816

VALVES		/ HYDRAULIC				IDENTIFICATION NUMBER 2-1-70		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GM	WEIBULL	235410.87	0.0	189933.99	456807.08	0.495	0.716	0.937

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GM	1	5	297405.	IMPROPER SEALING SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.318

5.5 Weibull Analyses -- Project 3. This section presents the results of fitting the Weibull distribution to nonelectronic part lifetimes collected from an air defense, ground fixed system. For a description of the tables presented in this section, refer to section 5.3.

The part classes/types for which the observed significance level was below 0.05 (supporting the Weibull over the exponential at the 0.05 level of significance) are listed below.

Part Class	Type	Significance Level	Shape Parameter Estimate
Drive for Computer Tapes	Magnetic Tape Drive	0.028	4.649
Track Ball	Electromechanical	< 0.0005	2.319

5.5.1 Weibull Analyses Summaries. Following is an index of the nonelectronic parts analyzed in this section. See Section 5.3.1 for a description of the entries of this index.

Index to Project 3 Weibull Analyses

Part Name	Part Type	Environment	Sequence Number	Best Fit
BELT	TIMING	GF	1	E
BLOWERS & FANS	AXIAL	GF	2	E
BLOWERS & FANS	CENTRIFUGAL	GF	3	E
CAMERA	TV	GF	4	E
COMPUTER MASS MEMORY	FIXED HEAD DISK MEMORY	GF	5	E
COMPUTER MASS MEMORY	MAGNETIC TAPE	GF	6	E
COMPUTER MASS MEMORY	MOVABLE HEAD DISK	GF	7	E
DRIVE FOR COMPUTER TAPES/DISCS	DISCS	GF	8	E
DRIVE FOR COMPUTER TAPES/DISCS	MAGNETIC TAPE DRIVE	GF	9	W
FILTERS	AIR	GF	10	E
HIGH SPEED PRINTERS	IMPACT	GF	11	E
KEYBOARD	ELECTROMECHANICAL	GF	12	E
LOW SPEED PRINTERS	DOT MATRIX	GF	13	E
MOTOR, ELECTRIC	SERVO, DC	GF	14	E
PULLEY	GEAR, BELT	GF	15	E
PUMP	PNEUMATIC	GF	16	E
PUMP	VACUUM	GF	17	E
SENSOR/TRANSDUCER/TRANSMITTER	PRESURE	GF	18	E
SENSOR/TRANSDUCER/TRANSMITTER	TEMPERATURE	GF	19	E
SWITCH	PRESSURE	GF	20	E
SWITCH	ROCKER	GF	21	E
SWITCH	THERMOSTATIC	GF	22	E
SWITCH	THUMBWHEEL	GF	23	E
TRACK BALL	ELECTROMECHANICAL	GF	24	W

BELT	/ TIMING					IDENTIFICATION NUMBER 3-1- 1		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	43941.38	20040.97	49527.46	79013.96	1.267	1.910	2.554

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	6	1386500.	DUE TO EXCESSIVE USE SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.146

BLOWERS & FANS	/ AXIAL					IDENTIFICATION NUMBER 3-1- 2		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	127945.26	14379.14	129342.22	244305.29	0.707	1.027	1.347

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	7	972930.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.943

BLOWERS & FANS / CENTRIFUGAL — IDENTIFICATION NUMBER 3-3- 3

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	193218.87	43916.16	204932.58	365948.99	0.878	1.189	1.501

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	8	2822220.	DEFECTIVE SENSOR SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.591

CAMERA / T V — IDENTIFICATION NUMBER 3-1- 4

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	264889.87	0.0	262206.68	603822.75	0.613	0.977	1.340

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	5	1213498.	DEFECTIVE POWER SUPPLY SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.958

COMPUTER MASS MEMORY / FIXED HEAD DISK MEMORY						IDENTIFICATION NUMBER 3-3- 5		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	91718.40	51064.13	99837.22	148610.31	1.028	1.336	1.645

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	9	1735360.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.324

COMPUTER MASS MEMORY / MAGNETIC TAPE						IDENTIFICATION NUMBER 3-3- 6		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	274772.53	155580.66	285606.52	415632.39	0.954	1.110	1.266

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	28	11224044.	DEFECTIVE SENSOR SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.542

COMPUTER MASS MEMORY / MOVABLE HEAD DISK — IDENTIFICATION NUMBER 3-1- 7

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	27646.90	17636.62	31196.55	44756.48	1.569	2.358	3.148

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	6	998280.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.060

DRIVE FOR COMPUTER TAPES/DISCS/ DISCS — IDENTIFICATION NUMBER 3-1- 8

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	20502.52	14032.96	22584.47	31135.98	1.915	4.111	6.308

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	2	377910.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.085

DRIVE FOR COMPUTER TAPES/DISCS/ MAGNETIC TAPE DRIVE — IDENTIFICATION NUMBER 3-1- 9

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	38707.09	27147.14	42334.91	57522.69	2.534	4.649	6.765

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	3	2095632.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.028

FILTERS / AIR — IDENTIFICATION NUMBER 3-1-10

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	58780.63	646.53	62802.44	124958.35	0.647	1.224	1.801

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	3	290320.	DAMAGED SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.728

HIGH SPEED PRINTERS / IMPACT						IDENTIFICATION NUMBER 3-3-11		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	7644.37	5787.38	8531.28	11275.19	1.163	1.611	2.058

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	7	106750.	DEFECTIVE IC SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.196

KEYBOARD / ELECTROMECHANICAL						IDENTIFICATION NUMBER 3-3-12		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	211230.96	0.0	228449.22	588391.99	0.669	1.293	1.916

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	3	1735620.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.668

LOW SPEED PRINTERS / DOT MATRIX — IDENTIFICATION NUMBER 3-3-13

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	70051.86	43692.92	77545.46	111398.00	1.153	1.492	1.830

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	8	1496250.	FUSE BLOWN OUT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.185

MOTOR,ELECTRIC / SERVO,DC — IDENTIFICATION NUMBER 3-1-14

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	741309.54	0.0	599300.01	1591129.00	0.451	0.718	0.984

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	5	910840.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.427

PULLEY		/ GEAR BELT				IDENTIFICATION NUMBER 3-1-15		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	46517.77	7266.77	52526.13	97785.49	1.140	2.188	3.235

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	3	1249110.	DUE TO EXCESSIVE USE SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.225

PUMP		/ PNEUMATIC				IDENTIFICATION NUMBER 3-1-16		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	86950.69	40540.86	95710.03	150879.19	1.027	1.430	1.834

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	6	1304767.	DEFECTIVE COMPONENTS SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.332

PUMP / VACUUM — IDENTIFICATION NUMBER 3-1-17

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	9236.81	7571.16	10258.59	12946.01	1.091	3.548	6.005

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	1	19132.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.218

SENSOR/TRANSDUCER/TRANSMITTER / PRESSURE — IDENTIFICATION NUMBER 3-1-18

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	226790.74	51892.87	248791.11	445689.36	1.008	1.399	1.789

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	7	5196390.	NO TAPE LOADING SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.350

SENSOR/TRANSDUCER/TRANSMITTER / TEMPERATIVE — IDENTIFICATION NUMBER 3-1-19

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	345074.16	0.0	186319.12	524388.85	0.278	0.522	0.767

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	3	116635.	PRINTER INOPERATIVE SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.188

SWITCH / PRESSURE — IDENTIFICATION NUMBER 3-1-20

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	63917.24	0.0	72067.57	160814.47	0.795	1.933	3.072

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	2	957050.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.397

SWITCH / ROCKER — IDENTIFICATION NUMBER 3-1-21

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	996681.35	0.0	1104908.26	3096761.48	0.943	1.510	2.076

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	5	62505757.	DEFECTIVE WIRING SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.388

SWITCH / THERMOSTATIC — IDENTIFICATION NUMBER 3-1-22

ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	1298702.01	0.0	1397896.50	4338015.14	0.734	1.264	1.794

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	4	20703888.	UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.651

SWITCH / THUMBWHEEL						IDENTIFICATION NUMBER 3-1-23		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	40932.97	1660.29	46198.29	90736.30	0.842	2.027	3.213

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	2	466416.	DAMAGED SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.384

TRACK BALL / ELECTROMECHANICAL						IDENTIFICATION NUMBER 3-3-24		
ENV	DIST. TYPE	MEAN ESTIMATE	80% LOWER BOUND	SCALE POINT ESTIMATE	80% UPPER BOUND	80% LOWER BOUND	SHAPE POINT ESTIMATE	80% UPPER BOUND
GF	WEIBULL	86684.26	57744.82	97837.46	137930.10	1.928	2.319	2.710

ENV	NUMBER OF SOURCES	NUMBER OF PARTS FAILED	TOTAL PART OPERATING HOURS	COMMENTS
GF	1	22	51605371.	DEFECTIVE COMPONENT SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.000

5.6 Part Malfunction Data. Table 5.6.1 gives the malfunction data and frequency of occurrence for each part name based only on the information which was available when the part failure data was collected. The malfunction data for each part name are accumulated over all use environments and part types for the particular part name.

Not all malfunctions reported are mutually exclusive. For example, "improper adjustment" and "improperly installed" may overlap. We leave it to the reader to combine the malfunction data into categories, as needed, using the information presented.

Table 5.6.1. PART MALFUNCTION DATA

PART NAME	MALFUNCTION	FREQUENCY OF OCCURRENCE %
ACCELEROMETER		
	DEFECTIVE PARTS INSIDE	100.0
ACTUATOR		
	BEARING & BRAKE RUSTED	6.7
	CABLE INSULATION FRAYED	6.7
	CABLE SLEEVE NEEDS FIXING	6.7
	IMPROPER CONFIGURATION SHOULD BE -2	6.7
	IMPROPER CONNECTOR INSTALLED	6.7
	REQUIRES ADJUSTMENT OF TM	6.7
	REQUIRES OVERHAUL	6.7
	SAFETY WIRE BRACKET BROKEN	6.7
	THERMAL SWITCH FOUND TO BE DEFECTIVE	6.7
	UNKNOWN	40.0
ANTENNA		
	UNKNOWN	100.0
AXLE		
	DAMAGED	50.0
	UNKNOWN	50.0
AZIMUTH ENCODER		
	ANTENNA WON'T MOVE	32.3
	CASING ROTATES	3.2
	CRACKED GLASS DISC	3.2
	ENCODER MARKING SHOULD BE REMOVED	3.2
	INCORRECT ANTENNA ROTATION	3.2
	LAMP DESIGN DEFECTIVE	3.2
	NO MOVEMENT BETWEEN DWELLS	3.2
	OPTICAL ASSEMBLY DEFECTIVE	3.2
	RESISTER IS DEFECTIVE	3.2
	UNKNOWN	41.9
BATTERY		
	CONNECTOR PANEL DEFECTIVE	20.0
	CONNECTOR PINS SHORTED	20.0
	CONNECTOR SHORTED	20.0
	K-1 MISWIRED	20.0
	SHORTED VR1-3 TO CHASSIS	20.0

Table 5.6.1, continued. PART MALFUNCTION DATA

PART NAME	MALFUNCTION	FREQUENCY OF OCCURRENCE %
BEARING		
	AZIMUTH DRIVE INOPERATIVE	4.2
	BLOWER BEARINGS WORN OUT	4.2
	BLOWER INOPERATIVE	4.2
	DEFECTIVE	4.2
	EXCESSIVE PLAY	12.5
	LUBRICATION DRIED OUT	4.2
	PRINTER INOPERATIVE	4.2
	REQUIRES OVERHAUL	12.5
	UNKNOWN.	45.8
	WLW HAS EXCESSIVE WEIGHT	4.2
BELLOWS		
	CRACKED	50.0
	UNKNOWN	50.0
BELT		
	BROKEN	10.0
	DUE TO EXCESSIVE USE	60.0
	WORN OUT	30.0
BLOWERS & FANS		
	BEARINGS WORN OUT	15.8
	DEFECTIVE SENSOR	18.4
	DEFECTIVE SWITCH	2.6
	EXCESSIVE CURRENT HAS SHORTED	2.6
	EXCESSIVE VIBRATIONS & BEARINGS LOOSE	5.3
	HAS EXCESSIVE VIBRATIONS & MOUNT IS LOOSE	5.3
	IMPROPER INSTALLATION	2.6
	MOTOR DAMAGED	2.6
	NOISY DUE TO DEFECTIVE BEARINGS	5.3
	REVERSE WIRING	2.6
	SHORTED	5.3
	SWITCH IS LOOSE	2.6
	SWITCH NOT PROPERLY INSTALLED	2.6
	SWITCH NOT WORKING	2.6
	UNKNOWN	23.7

Table 5.6.1, continued. PART MALFUNCTION DATA

PART NAME	MALFUNCTION	FREQUENCY OF OCCURRENCE %
BRAKES		
	ASSY SCREW TOO TIGHT	2.3
	BRAKE CABLE TOO SHORT	2.3
	BRAKE DISCS WORN OUT	2.3
	BRAKE PAD BUSHINGS SCREW LOOSE	2.3
	BRAKES CORRODED	4.7
	EXCESSIVE GAP	18.6
	IMPROPER ADJUSTMENT	7.0
	IMPROPER POSITIONING	4.7
	IMPPOPERLY INSTALLED	2.3
	LOCK SCREW NEEDS REPLACEMENT	2.3
	NEEDS ADJUSTMENT	18.6
	PARTS ARE WORN OUT	2.3
	PARTS BROKEN	2.3
	RECRIMP TERMINAL D&C REQUIRED	2.3
	SCREW LOOSE	2.3
	UNKNOWN	20.9
	WORN OUT	2.3
BRUSHES		
	NEEDS ADJUSTMENT	66.7
	SHORTED	33.3
BUSHINGS		
	UNKNOWN	16.7
	WORN OUT	83.3
CAMERA		
	DEFECTIVE POWER SUPPLY	40.0
	PICTURE BECOMES WEAK & BREAKS UP	20.0
	UNKNOWN	40.0
CIRCUIT PROTECTION DEVICE		
	PAINT STENCILED ON ARRESTER SHORTED	14.3
	UNKNOWN	85.7
CLUTCH		
	ANTENNA FAILS TO ROTATE	62.5
	ANTENNA MOVES SLOWLY	12.5
	NEEDS ADJUSTMENT	25.0
COMPUTER MASS MEMORY		

Table 5.6.1, continued. PART MALFUNCTION DATA

PART NAME	MALFUNCTION	FREQUENCY OF OCCURRENCE %
	BAD REEL HUB ASSEMBLY	1.0
	BAD SOLDER JOINTS ON CONNECTOR PINS	1.0
	CABLE WIRES SWITCHED	1.0
	CAPSTAN MOTOR DEFECTIVE	1.0
	CAPSTAN MOTOR JAMMED	1.0
	CONNECTOR PINS HAVE BROKEN	1.0
	DEFECTIVE CAPACITOR	2.0
	DEFECTIVE CCA	1.0
	DEFECTIVE CHECK VALVE	1.0
	DEFECTIVE CONTROL SYSTEM	1.0
	DEFECTIVE DISC	1.0
	DEFECTIVE IC	6.9
	DEFECTIVE MOTOR ASSEMBLY	1.0
	DEFECTIVE POWER SUPPLY	1.0
	DEFECTIVE SENSOR	14.9
	DEFECTIVE SOLDERING ON IC.	2.0
	DEFECTIVE TRANSISTOR	3.0
	DEFECTIVE TRANSISTOR IN SERVO ASSEMBLY	1.0
	DEFECTIVE VACUUM CHAMBER SENSOR	1.0
	FLOPPY DRIVE ONE IS DEFECTIVE	1.0
	FUSE BLOWN	1.0
	HAS LOW PRESSURE	2.0
	MTC DEFECTIVE	1.0
	PINS 1 & 3 ARE DAMAGED	1.0
	POWER SUPPL DEFECTIVE	1.0
	Q1 & Q2 IMPROPERLY ORIENTED	1.0
	READ/WRITE HEAD IS DEFECTIVE	1.0
	RIBBON CABLE BROKEN	1.0
	SERVO AMP. DEFECTIVE	1.0
	TWO PINS SHORTED ON CONNECTOR	1.0
	UNKNOWN	8.9
	WON'T ACCEPT CERTAIN PROGRAMS	1.0
	WON'T ACCEPT VRS-131	1.0
	WON'T LOAD	19.8
	WON'T RECORD	4.0
	WON'T REWIND	9.9
	WRONG FUSE WAS INSTALLED	1.0
COUPLING		
	UNKNOWN	100.0
CRANK SHAFT		
	BRACKET BROKEN	40.0

Table 5.6.1, continued. PART MALFUNCTION DATA

PART NAME	MALFUNCTION	FREQUENCY OF OCCURRENCE %
	UNKNOWN	60.0
DIAPHRAGMS BURST		
	UNKNOWN	100.0
DRIVE FOR COMPUTER TAPES/DISCS		
	DATA LOST FROM TAPES	2.3
	DEFECTIVE	25.6
	DEFECTIVE IC	2.3
	LOOSE CONNECTION	4.7
	UNKNOWN	65.1
DRIVES (GEAR)		
	IMPROPER ADJUSTMENT	30.0
	IMPROPER INSTALLATIONS	10.0
	NEEDS REPLACEMENT	10.0
	UNKNOWN	30.0
	WORN OUT	20.0
DRUM		
	BAD ROTATION AFTER DROP TEST	4.3
	BRACKET BROKEN	4.3
	CONNECTOR P-4 DEFECTIVE	4.3
	DAMAGED DUE TO OVERSPEED & MANY IMPACTS	4.3
	DRUM HAS EXCESSIVE WEIGHT BEARING DAMAGE	4.3
	DRUM OUT OF ALIGNMENT	8.7
	DRUM STICKS	30.4
	HAS OPEN TACH WINDING	4.3
	NOT PROPERLY ALIGNED	4.3
	SERVO AMP FOUND TO BE DEFECTIVE	4.3
	UNKNOWN	26.1
DUCT		
	CRACKED	30.0
	IMPROPERLY INSTALLED	10.0
	UNKNOWN	20.0
	USED UP. NEEDS REPLACEMENT	40.0
ELECTRIC HEATERS		

Table 5.6.1, continued. PART MALFUNCTION DATA

PART NAME	MALFUNCTION	FREQUENCY OF OCCURRENCE %
	SHORTED	40.0
	UNKNOWN	60.0
ELECTROMECHANICAL TIMERS		
	NEEDS ADJUSTMENT	33.3
	UNKNOWN	66.7
FILTER		
	DAMAGED	16.7
	LEAKING	38.9
	LINE FILTER PIN-D OPEN	5.6
	NEEDS REPLACEMENT	11.1
	UNKNOWN	27.8
FITTINGS		
	IMPROPER ADJUSTMENT	7.1
	LEAKING	28.6
	NEEDS CLEANING	7.1
	UNKNOWN	57.1
FUSE HOLDER		
	DAMAGED	100.0
GASKETS & SEALS		
	BAD INTERNAL SEAL IN GEAR DRIVE	6.7
	IMPROPER INSTALLATION	6.7
	LEAKING	6.7
	NEEDS REPLACEMENT	46.7
	POPS UP DURING ANTENNA MOVEMENT	6.7
	UNKNOWN	26.7
GEAR		
	UNKNOWN	60.0
	WORN OUT	40.0
GEAR BOX		
	NEEDS OVERHAUL	33.3
	NO OIL IN GEAR BOX	66.7

Table 5.6.1, continued. PART MALFUNCTION DATA

PART NAME	MALFUNCTION	FRECUENCY OF OCCURRENCE %
HEAT EXCHANGERS		
	NEEDS ADJUSTMENT	20.0
	NEEDS REPLACEMENT	20.0
	NOT PROPERLY FABRICATED BY VENDOR	20.0
	UNKNOWN	40.0
HIGH SPEED PRINTERS		
	AC INPUT SHORTED	0.9
	AC INPUT SHORTED UNDER LOAD	0.9
	BEARINGS WORN OUT. REQUIRES REPLACEMENT	0.9
	BELT IS SLIPPING	0.9
	DEFECTIVE IC	10.5
	DEFECTIVE POTENTIOMETER	0.9
	DEFECTIVE SENSOR	1.8
	DEFECTIVE TRANSISTOR	3.5
	FEEDING MECHANISM NEEDS REPAIR	0.9
	HAMMER BLOWER NOISY	0.9
	HAMMER DRIVER DAMAGED	0.9
	HAMMER HEAD BROKEN	0.9
	HAS RIBBON SKEWING PROBLEM	0.9
	LOOSE PULLEY	2.6
	MOTOR & ROLLER ARE DEFECTIVE	0.9
	MOTOR DEFECTIVE	1.8
	MOTOR JAMMED	0.9
	MOTOR NOT WORKING PROPERLY	1.8
	MOTOR SHORTED	0.9
	NEEDS OVERHAUL	0.9
	NEEDS WIRE REPLACEMENT	0.9
	NO POWER AT - 32C	0.9
	OVER CURRENT, SHORTED	1.8
	PAPER FEED NOT WORKING	1.8
	PAPER FEEDING MECHANISM JAMMED	0.9
	PAPER SPINDLE ROTATION SLOW	0.9
	PAPER SPINDLE TENSION LOW	1.8
	PARTS MISSING	3.5
	PRINT FINGERS BENT	1.8
	PROBLEM WITH TAKE UP	0.9
	PULLEY BROKEN	0.9
	RESISTOR R-35, IS OPEN	0.9
	RIBBON MOTOR INOPERATIVE	0.9
	RIBBON WORN OUT	1.8
	RIBBON WORN OUT & BAD SWITCH	0.9
	ROLLER PRESSURE IS LOW-NEEDS ADJUSTMENT	0.9
	ROLLER PRESSURE NEEDS ADJUSTMENT	0.9

Table 5.6.1, continued. PART MALFUNCTION DATA

PART NAME	MALFUNCTION	FREQUENCY OF OCCURRENCE %
	STEPPER MOTOR DEFECTIVE	1.8
	STEPPER MOTOR IS INOPERATIVE	0.9
	TAKE UP REEL LATCH IS INOPERATIVE	1.8
	TIMING BELT & PULLEY WORN OUT	0.9
	TIMING BELT BROKEN	1.8
	TIMING BELT DAMAGED & WORN OUT	0.9
	TIMING BELT WORN OUT	1.8
	TOP ROLLER PRESSURE NEEDS ADJUSTMENT	0.9
	TRANSFORMER HAS OPEN LEAD	0.9
	UNKNOWN	32.5
HOSES		
	DEFECTIVE	28.6
	HOSE HAS CRACKS DUE TO ANTENNA MOVEMENT	42.9
	UNKNOWN	14.3
	WORN OUT	14.3
INSTRUMENTS		
	SEALING DAMAGED	20.0
	UNKNOWN	80.0
JOINT, MICROWAVE ROTARY		
	DEFECTIVE	40.0
	UNKNOWN	60.0
KEYBOARD		
	CABLE(GP554)DEFECTIVE	4.3
	IMPROPER CONNECTIONS	4.3
	LED DISPLAY DEFECTIVE	4.3
	LOCKED UP	13.0
	U-32 DEFECTIVE	4.3
	UNKNOWN	69.6
LOW SPEED PRINTERS		
	DEFECTIVE CAPACITOR	8.3
	DEFECTIVE IC	16.7
	DEFECTIVE RELAY	8.3
	DEFECTIVE SWITCH	8.3
	FUSE BLOWN OUT	33.3
	TEAR BAR BROKEN	8.3

Table 5.6.1, continued. PART MALFUNCTION DATA

PART NAME	MALFUNCTION	FREQUENCY OF OCCURRENCE %
	TERMINAL WILL NOT LINE FEED	8.3
	TRANSFORMER SHORTED	8.3
METAL TUBING		
	UNKNOWN	100.0
MOTOR, ELECTRIC		
	HAS OPEN TACH-WINDING	7.7
	PAPER TAKE UP UNEVEN	7.7
	SWITCH DEFECTIVE	15.4
	UNKNOWN	61.5
	WLU MAP DRUM OSCILLATES. DEMAGNETIZED	7.7
POWER CIRCUIT BREAKER		
	CONNECTOR DEFECTIVE	12.5
	IMPROPER CONNECTIONS	25.0
	UNKNOWN	62.5
POWER SWITCH GEAR		
	UNKNOWN	100.0
PULLEY		
	DUE TO EXCESSIVE USE	33.3
	PRINTER INOPERATIVE	22.2
	WORN OUT	44.4
PUMP		
	CIRCUIT BREAKER TRIPS	7.1
	DEFECTIVE CHECK VALVE	7.1
	DEFECTIVE COMPONENTS	21.4
	HAS HIGH 10N CURRENT	7.1
	LOW PRESSURE	14.3
	NEEDS ADJUSTMENT	7.1
	OUTPUT PRESSURE VERY LOW	7.1
	UNKNOWN	28.6
RESILIENT MOUNT		
	IMPROPER MOUNT	40.0

Table 5.6.1, continued. PART MALFUNCTION DATA

PART NAME	MALFUNCTION	FREQUENCY OF OCCURRENCE %
	SCREWS MISSING	20.0
	UNKNOWN	40.0
RETAINING RING		
	NEEDS ADJUSTMENT	33.3
	NEEDS REPLACEMENT	33.3
	UNKNOWN	33.3
SENSOR/TRANSDUCER/TRANSMITTER		
	NO TAPE LOADING	30.0
	PRINTER INOPERATIVE	30.0
	RELAY DEFECTIVE	20.0
	VACUUM COLUMN NOISY	20.0
SHAFT		
	HINGE REDESIGN REQUIRED	11.1
	RUST UNDER GUSSET	11.1
	UNIT HAD GREASE WHICH HAS FROZEN	11.1
	UNKNOWN	66.7
SHOCK ABSORBERS		
	IMPROPER MOUNT	50.0
	REQUIRES REFURBISHING	25.0
	UNKNOWN	25.0
SOLENOIDS		
	UNKNOWN	100.0
SWITCH		
	BRAKE INTERLOCK SYSTEM STUCK	1.6
	CONNECTION LOOSE	1.6
	CONNECTOR BASE PULLED OUT	1.6
	DAMAGED	4.8
	DEFECTIVE WIRING	4.8
	IMPROPER CONNECTION	3.2
	IMPROPER INSTALLATION	6.5
	IMPROPER WIRING	9.7
	IMPROPERLY BONDED	1.6
	LOOSE DUE TO EXCESSIVE VIBRATIONS	1.6

Table 5.6.1, continued. PART MALFUNCTION DATA

PART NAME	MALFUNCTION	FREQUENCY OF OCCURRENCE %
	LOOSE INSTALLATION	1.6
	LOW PRESSURE	1.6
	NEEDS REPOSITIONING	4.8
	NEEDS REWIRING	1.6
	OPEN	1.6
	Q-3 LEADS SHORTED	1.6
	REVERSED LEADS	1.6
	SHORTED	3.2
	SWITCH IS BENT	1.6
	UNKNOWN	43.5
TELESCOPE		
	DAMAGED	50.0
	UNKNOWN	50.0
TRACK BALL		
	CONSOLE CANNOT ENTER MODE BITE	3.2
	DEFECTIVE COMPONENT	67.7
	DEFECTIVE DIODE	3.2
	DEFECTIVE IC	3.2
	DEFECTIVE LAMP	9.7
	IMPROPER SOLDERING INSIDE	3.2
	LOOSE CONNECTOR	3.2
	UNKNOWN	6.5
VALVES		
	CRACKS ON BODY	12.5
	DUE TO LOW PRESSURE	12.5
	IMPROPER SEALING	12.5
	SEAL WORN OUT	37.5
	UNKNOWN	25.0

6.0 RELIABILITY DEMONSTRATION TESTS

6.1 Introduction. The purpose of a reliability demonstration test is to decide if additional reliability design effort is necessary to achieve the specified reliability for the nonelectronic item when it is operated in the field environment. The reliability specification (see section 3.0) identifies the parameter(s) and the values to be nominally and minimally acceptable. Reliability demonstrations are statistical hypothesis tests which lead to one of two mutually exclusive decisions:

(a) The reliability parameter(s) of the component is (are) acceptable and no additional design effort is required under the contract;

(b) The realiability parameter(s) of the component is (are) unacceptable and additional design effort is required.

The demonstration is designed to have a high probability that the decision reached is correct. When the decision is (a), the consumer runs the risk that the decision is incorrect, i.e. that (b) is true but there were an unusually low number of failures during the test. The probability of this type of incorrect decision is called the consumer's risk (β).

Similarly, the probability that the decision is (b) when (a) is true (i.e. the component has an unusually large number of failures during the test) is called the producer's risk (α).

It is important that the demonstration simulate the field environment or that there be a known relationship between the field environment and the test environment. For example, if the component actuation rate in the field is low and the effect of actuation rate is known, it would save test time to raise the actuation rate and lower the acceptable reliability values accordingly.

6.1.1 Statistical Characteristics of a Reliability Demonstration Test. There are six essential characteristics of a reliability demonstration test.

(1) The reliability parameter(s) in the specification. If the distribution of the number of failures in the period of time $[0,T]$ is available in a mathematical expression then the reliability parameters will be related to the distribution parameters.

(2) The acceptable values for the reliability parameter(s). For example, the upper test MTBF (θ_0) in MIL-STD-781C is the smallest desired value of MTBF.

(3) The unacceptable values for the reliability parameter(s). For example, the lower test MTBF (θ_1) in MIL-STD-781C is the largest unacceptable value for MTBF.

(4) The producer's risk, α.

(5) The consumer's risk, β.

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(a) The reliability parameter(s) of the component is (are) acceptable and no additional design effort is required under the contract;

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(4) The producer's risk, α.

(5) The consumer's risk, β.

(6) The sampling plan which defines how and what parameters will be observed, and the criterion for ending the demonstration test and reaching a decision.

In what follows, R will denote a generic reliability parameter (e.g. MTBF, probability of survival of a prespecified time period, etc.) larger values of which are preferred. The smallest acceptable value of R in (2) above is denoted by R_0, and the largest unacceptable value of R is denoted by R_1. R_0 must be strictly greater than R_1. The values of R which lie between R_1 and R_0 are called indifference values. The ratio R_0/R_1 is called the discrimination ratio.

The statistical characteristics of a demonstration are summarized in the operating characteristic (OC) relationship between R and the probability of passing the test when R is the "true" reliability, P(R). Characteristics (4) and (5) give two points in the OC relationship, namely $P(R_0)=(1-\alpha)$, and $P(R_1)=b$.

6.1.2 <u>Cost of Demonstration</u>. The cost of demonstration is determined by the number of samples collected and the calendar time the test facility is occupied. Cost efficient demonstrations require the smallest number of samples and the least calendar time to meet the risk objectives of the demonstration.

If the reliability parameters are related to the parameters of a life distribution, then the most cost efficient demonstration is to measure the time of failure (a variable) for each sample. The demonstration is then called a variables test and the sample of failure times provides the maximum information on the reliability of the design of the component. If the reliability parameter is the fraction of components in a lot which will live beyond some time T, the demonstration will attribute success or failure to each sample according to whether or not the component is operational at time T (attributes testing).

The rule for terminating the demonstration also affects the cost. Given the values for the characteristics in 6.1.1 (1)-(5), it is possible to design a fixed sample size (or fixed time) or sequential demonstration test. In a fixed sample demonstration test termination occurs when (i) all the sample values are observed or (ii) when enough failures have been observed to decide the reliability is unacceptable. Similarly, a fixed time demonstration terminates when (i) the fixed time limit is reached or (ii) when enough failures are observed to decide the reliability is unacceptable. During a sequential demonstration, a sequence of decision points for both acceptable and unacceptable reliability are formulated and a decision is reached the first time one of these decision points is reached. On the average a sequential demonstration will require a smaller sample than a fixed sample test for the same R_0, R_1, α, b. Sequential demonstrations are possible for both variables and attributes testing.

6.1.3 <u>Sample Size limitations</u>. In general sample size (N) (or average sample size, for sequential demonstration tests) is the dependent variable of

a reliability demonstration (i.e. the demonstration characteristics in 6.1.1 (1)-(5) are allowed to determine N). N increases as either the discrimination ratio, α, or β decrease. There is a maximum value for N (NMAX) in all practical situations. If the N required by the characteristics of 6.1.1 (1)-(5) exceeds NMAX, one of the parameters (usually α) must be changed (R_0, α, or β can be increased, or R_1 can be decreased).

6.1.4 Summary. The remainder of this section presents step-by-step instructions on the use of various types of reliability demonstration test plans. The section is arranged to present first test plans based on attributes, followed by variables test plans.

6.2 Attributes Demonstration Tests

6.2.1 Attributes Plans for Small Lots

1. When to use

When testing parts from a small lot where the accept/reject decision for the lot is based on attributes, the hypergeometric distribution is applicable. Attributes tests should be used when the parameter of interest is the fraction of components in a lot which possess a certain reliability attribute.

The example demonstrating the method is based on a small lot and small sample size. This situation frequently characterizes the demonstration test problem associated with nonelectronic parts. The sample size limits the discriminatory power of the demonstration test plan but frequently cost and time constraints force us into larger than desired risks.

2. Conditions for Use

The attribute of interest may be that a part survives at least t hours. A "success" for a component tested would be that it survives t hours. The parameter to be evaluated then is the fraction of the parts in the lot whose lives would exceed t hours.The estimation of the parameter would be based on a fixed sample size and testing without replacement. The selection of the criteria for success (t hours) can be derived from a requirement (such as mission length, for example). If the lot size is 30 or more, then the Poisson approximation may be used to make the calculation simpler. (See Section 6.2.3).

3. Method / Example

Method	Example
a. Define criterion for success/failure, i.e. define the attribute.	a. A part that lasts 100 or more hours on a given life test is considered a success. Parts failing before 100 hours are considered failures.

3. Method | Example

Method	Example
b. Define acceptable lot quality level ($1-p_o$).	b. Lots in which ($1-p_o$) = 90% of of the parts will survive 100 hours are to be accepted by this demonstration test plan with high probability.
c. Specify producer's risk (α) (i.e, the probability that acceptable lots be rejected).	c. Let $\alpha = .2$. This decision is an engineering one based on the consequences of allowing defective lots to be accepted and based on the time and dollar constraints associated with inspecting the lot.
d. Define unacceptable quality level ($1-p_1$).	d. Lots in which only $1-p_1$ = 20% of the parts will survive 100 hours will be accepted by the demonstrations test plan with low probability.
e. Specify the consumer's risk (β) (i.e., the probability that unacceptable quality lots will pass the demonstration test).	e. Let $\beta = .022$ (Taken for convenience in calculations).
f. Now that α, β, $1-p_o$, and $1-p_1$ have been specified the following steps describe the calculations required to determine the sample size and accept/reject criteria which will satisfy the stated risks.	f. Given: lot size N=10 $1-p_o = .9$ $1-p_1 = .2$ $\alpha = .2$ $\beta = .022$
g. The process consists of a trial and error solution of the hypergeometric equation using N, $1-p_o$, $1-p_1$ and various sample sizes until the conditions of α and β are	g. The calculations are as follows: If N = 10 and it is assumed that samples are taken from a lot with $1-p_o = .9$ then that lot contains 9 good parts and 1 defective part. As the

3. <u>Method</u> / <u>Example</u>

Method

g. met. The equation used is

$$Pr(x) = \frac{\binom{r}{x}\binom{N-r}{n-x}}{\binom{N}{n}}$$

$x = \max(0, n-N+r), 1, 2 \ldots \min(n,r)$

where x = number of successes in sample
r = number of successes in lot
N = lot size
n = sample size

$$\binom{r}{x} = \frac{r!}{x!(r-x)!}$$

h. Find the number of successes which satisfies α and β in the calculations involving $1-p_o$ and $1-p_1$.

Example

first step in the trial and error procedure assume a sample size of 2. The possible outcomes are either 0, 1 or 2 good parts. The probability of each outcome using the hypergeometric formula is

$$Pr(2) = \frac{\binom{9}{2}\binom{1}{0}}{\binom{10}{2}} = .8$$

$Pr(1) = .2$
$Pr(0) = 0$

The same calculations for $1-p_1 = .2$ results in

$Pr(2) = .022$
$Pr(1) = .356$
$Pr(0) = .622$

h. From these 2 sets of results it can be seen that if a sample size of 2 is specified, then α and β will be satisfied if the decision rule is made that if 2 successes are observed in the sample the lot is accepted and for all other outcomes the lot is rejected.

If $1-p_o = .9$, then $Pr(2) = .8$, therefore $1-.8 = .2 = \alpha$ If $1-p_1 = .2$, then $Pr(2) = .022 = \beta$.

NOTE: A different sample size can be traded off against different α, β, $1-p_o$, $1-p_1$.

3. Method

i. The demonstration test is then specified.

Example

i. The test procedure is as follows:

1. Test a random sample of 2 parts from a lot of 10 parts for 100 hours.

2. If both parts survive 100 hours, accept the lot.

3. If only 0 or 1 parts survive 100 hours reject the lot.

4. For Further Information.

There are "Tables of the Hypergeometric Distribution" by G. J. Lieberman and D. B. Owen, Stanford University Press, Stanford, California, 1961 to perform the mathematical calculations of Step g. Also if N becomes large (say 30 or more) then the binomial or the Poisson distribution can be used as an approximation for the hypergeometric distribution.

6.2.2 Attributes Plans for Large Lots (Binomial)

1. When to Use

When testing parts from a large lot where the accept/reject decision for the lot is based on attributes, the binomial distribution is applicable. Strictly speaking, all reliability attributes testing should follow the hypergeometric distribution as long as individual parts are placed on test and tested to failure without replacement. However, when the lot size is large, the binomial distribution is a good approximation for the hypergeometric and therefore the example presented in this section covers the use of the binomial. Attributes test should be used when the parameter of interest is the fraction of components in a lot which possess a certain reliability attribute.

2. Conditions for Use

The attribute of interest may be that a part survives for at least t hours. A "success" for a component tested would be that it survives t hours. The parameter to be evaluated then is the fraction of the parts in the lot that would survive t hours. The estimation of the parameter would be based on a fixed sample size and testing without replacement. The selection of the criteria for success (t hours) can be derived from a requirement (such as a mission length, for example).

3. Method / Example

Method	Example
a. Define criterion for success/failure, i.e. define the attribute.	a. A part that lasts 100 or more hours on a given life test is considered a success. Parts failing before 100 hours are considered failures.
b. Define acceptable lot quality level ($1-p_o$).	b. Lots in which $1-p_o = .9$ (i.e., the life of 90% of the parts will exceed 100 hours) are to be accepted by this demonstration test plan with high probability.
c. Specify producer's risk (α) (i.e., the probability that acceptable lots will be rejected).	c. let $\alpha = .01$.
d. Define unacceptable lot quality level ($1-p_1$).	d. Lots with only a true fraction of acceptable parts $1-p_1 = .5$ are to be accepted by this demonstration test plan with low probability.
e. Specify consumer's risk (β). (i.e., the probability that lots of unacceptable quality level will be accepted).	e. let $\beta = .17$ (selected for ease of calculation).
f. Now that α, β, $1-p_o$, and $1-p_1$ have been specified, the following steps describe the calculations required to determine the sample size and accept/reject criteria which will satisfy the stated risks.	f. Given: lot size N = large say > 30 $1-p_o = .9$ $1-p_1 = .5$ $\alpha = .01$ $\beta = .17$
g. The process now consists of a trial and error solution of the binomial equation using $1-p_o$, $1-p_1$ and various sample sizes until at a given decision point, the conditions of α and β are	g. Assume a random sample of size $n = 10$ is taken from a lot whose true fraction of good parts is .9. Solve the binomial equation for the total number of consecutive outcomes whose summed probabilities equal

3. Method	Example
g. satisfied. The binomial equation is:	α starting at 0 successes. The calculations for this decision point are:

$$Pr(x) = \binom{n}{x} (1-p)^x (p)^{n-x}$$

where n = sample size
x = observed successes in sample
p = lot fraction defective

$$Pr(10) = \binom{10}{10}(.9)^{10}(.1)^0 = .3486$$

Pr(9) = .387
Pr(8) = .1935
Pr(7) = .0574
Pr(7 or more) = .9865

Then

Pr(6 or less) = 1-Pr (7 or more)
= 1.0 - .9865
≈ .01 (which satisfies the α risk).

Perform the same type of calculations assuming the true fraction defective is .5. In this instance sum the probabilities starting at 10 successes until succeeding consecutive probabilities sum to the value of β. This yields the following results:

$$Pr(10) = \binom{10}{10}(.5)^{10}(.5)^0 = .001$$

Pr(9) = .010
Pr(8) = .044
Pr(7) = .117
Pr(7 or more) ≈ .17 (which satisfies the β risk)

h. The demonstration test is then specified.	h. The test procedure is as follows:

1. Test a random sample of 10 parts for 100 hours.

3. Method

h.

Example

2. If 7 or more parts survive 100 hours, accept the lot.

3. If 6 or less successes are observed, reject the lot.

4. For Further Information

There are several published tables for use in determining binomial probabilities in the event that the sample size makes calculations too lengthy. One of these is Tables of the Binomial Probability Distribution, National Bureau of Standards, Applied Mathematics Series 6, Washington, D.C., 1950. It gives individual terms and the distribution function for $p = .01$ to $p = .50$ in graduations of .01 and $n = 2$ to $n = 49$ in graduations of 1.

6.2.3 Attributes Demonstration Test Plans for Large Lots (The Poisson Approximation Method)

1. When to Use

In attributes demonstration test plans if the lot size gets much above 100 the calculations required to generate a demonstration test plan become very time consuming. The Poisson distribution can be used as an approximation of both the hypergeometric and the binomial distributions if the lot size is large and if the fraction defective in the lot is small. This method can therefore be used in lieu of the previous two methods in many cases.

2. Conditions for Use

If the lot size is large and the fraction defective is small, this method is applicable. Its use is initiated by specifying a desired producer's risk, consumer's risk, acceptable lot fraction defective and unacceptable lot fraction defective. As before, it is also necessary to specify the characteristics that constitute a defective part since this is an attributes type test.

3. Method

a. Define criterion for success/failure.

Example

a. A part that lasts 100 or more hours on a given life test is considered a success. Parts failing before 100 hours are considered failures.

3. | Method | Example |
|---|---|
| b. Define acceptable lot quality level $(1-p_o)$. | b. Lots in which $1-p_o = .9$ (the life of 90% of the parts in the lot will exceed 100 hours) are to be accepted by this demonstration test plan with high probability. |
| c. Specify the producer's risk (α) (i.e., the probability that acceptable lots will be rejected). | c. Select $\alpha = .05$. |
| d. Define unacceptable lot quality level $(1-p_1)$. | d. Lots with only a true fraction of acceptable parts $1-p_1 = .75$ are to be accepted by this demonstration test plan with low probability. |
| e. Specify the Consumer's risk β (i.e. the probability that lots of unacceptable quality level will be accepted by this plan). | e. Select $\beta = .02$. |
| f. Now that α, β, $1-p_o$, and $1-p_1$ have been specified, the accept/reject criteria are determined by the following formulas: | f. Given: lot size N=1000
$1-p_0 = .90$
$1-p_1 = .75$
$\alpha = .05$
$\beta = .02$ |

$$1 - \alpha = \sum_{x=0}^{c} \frac{(np_0)^x \exp(-np_0)}{x!}$$

$$\beta = \sum_{x=0}^{c} \frac{(np_1)^x \exp(-np_1)}{x!}$$

g. The solution now consists of trying various values of n in the above formulas until they are approximately satisfied.	g. Assume n = (sample size) = 100. Then, $np_0 = 100\ (.10) = 10$ $np_1 = 100\ (.25) = 25.$ Using a digital computer to

3. Method | Example

compute the formulas in (f) above leads to c=15, and

$\alpha = .049$

$\beta = .022.$

The decision criterion is now specified as c=15 or less failures.

h. The demonstration is then fully specified.

The demonstration test procedure is as follows:

1) Take a random sample of 100 parts from the lot of size 1000 and test each part for 100 hours.

2) If 15 or less fail to survive 100 hours, accept the lot. If more than 15 parts fail to survive 100 hours, reject the lot.

4. For additional examples using this method, refer to E.B. Grant, Statistical Quality Control, McGraw Hill, 1964.

6.2.4 Attributes Sampling Using MIL-STD-105D

1. When to Use

When the accept/reject criteria for a part is based on attributes decisions MIL-STD-105D is a useful tool. These sampling plans are keyed to fixed AQL's (Acceptable Quality Level) and are expressed in lot size, sample size, AQL and acceptance number. Plans are available for single sampling, double sampling and multiple sampling. The decision as to which type to use is based on a trade-off between the average amount of inspection, the administrative cost and the information yielded regarding lot quality. For example, single sampling usually results in the greatest amount of inspection, but this can be offset by the fact that it requires less training of personnel, and record keeping is simpler, and it gives a greater amount of information regarding the lot being sampled. The main difference between MIL-STD-105D plans and the previous plans is that the unacceptable quality level need not be specified.

2. Conditions for Use:

The user of a MIL-STD-105D sampling plan must have items a and b below. MIL-STD-105D will determine items c, d, and e below, for a given type of sampling type (i.e. single, double, multiple, etc.):

a. Lot Size
b. Acceptable Quality Level
c. Sample Size

d. Acceptance Number
e. Criteria for Acceptance or Rejection.

The specification of the AQL is an engineering decision based on the fraction defective that a user of parts considers acceptable. Lots with this percent defective will be accepted a high fraction of the time. Operating characteristic curves are supplied with each sampling plan and these can be used to evaluate the protection afforded by the plan for various quality levels.

MIL-STD-105D also contains plans for normal, tightened and reduced inspection plans which can be invoked if the fraction defective of lots seems to be varying or trending.

3. Method	Example
a. Determine lot size and specify AQL and type of sampling.	a. Given a lot containing 100 parts and an AQL is specified at 6.5% with single sampling specified.
b. Enter the table with lot size and select the sample size code letter.	b. From Table I (Sample Size Code Letters) on page 9, MIL-STD-105D, find the sample size code letter for a lot of size 100. For this example and for normal sampling, the specified code number is F (General inspection level II is the default).
c. Enter the single sampling plan table for normal inspection with the code number from Step b.	c. Enter Table II-A (Single Sampling Plans for Normal Inspection) page 10 with code letter F. Under the column titled Sample Size, find the number 20 in the same row as the letter F. This is the number of parts to be randomly selected and inspected.
d. Enter the same table in the proper column for the specified AQL.	d. Find the column in Table II-A page 10 corresponding to an AQL of 6.5%.

3. Method	Example
e. Proceed horizontally along the Sample Size Code Number row until it intersects with the AQL column to obtain the acceptance number.	e. At the intersection of row F and column 6.5%, the acceptance number is 3 and the rejection number is 4.
f. The Single Sampling Plan from MIL-STD-105D is to select a random sample of size n from a lot of size N, inspect it and accept the lot if the number of defectives in the lot is equal to or less than the Acceptance Number. If the observed number of defects is equal to or greater than the rejection number, the lot is rejected.	f. For the single sampling plan N = 100, AQL = 6.5%, select a random sample of size n = 20 and inspect it for attributes criteria. If 3 or less defectives are found in the sample accept the lot. If 4 or more defectives are found in the sample reject the lot.

4. For Further Information

In addition to the example discussed above, MIL-STD-105D contains other plans for any lot size and for selected AQL's from .01 to 1000% (AQL's over 10% are defects per hundred units, rather than percent of defective units). MIL-STD-105D also presents operating characteristic curves for each sampling plan.

6.2.5 Sequential Binomial Test Plans

1. When to Use

When the accept/reject criterion for the parts on test is based on attributes, and when the exact test time available and sample size to be used are not known or specified then this type of test plan is useful. The test procedure consists of testing parts one at a time and classifying the tested parts as good or defective. After each part is tested, calculations are made based on the test data generated to that point and the decision is made either that the test has been passed, failed, or that another observation should be made. A sequential test will result in a shorter average number of parts tested than either failure truncated or time truncated tests when the lot tested has a fraction defective at or close to p_0 or p_1.

2. Conditions for Use

a. The parts subjected to test will be classified as either good or defective. In other words, testing will be by attributes.

b. The acceptable fraction defective in the lot p_0, the unacceptable fraction defective p_1, the producer's risk α, and consumer's risk β must be specified.

c. The test procedure will be to test one part at a time. After the part fails or its test time is sufficient to classify it as a success, the decision to accept, reject or continue testing the lot will be made.

d. The part lot size must be large (greater than 100).

3. Method

a. Specify p_0, p_1, α, β

b. Calculate decision points with the following formula

$$\frac{1-\beta}{\alpha} \text{ and } \frac{\beta}{1-\alpha}$$

c. As each part is tested, classify it as a failure or a success and evaluate the expression:

$$(p_1/p_0)^f((1-p_1)/(1-p_0))^s$$

where f = total number of failures

s = total number of successes.

If at some point, this expression exceeds $(1-\beta)/\alpha$ reject the lot. If at some point, this expression is less than $\beta/(1-\alpha)$ accept the lot. Continue

Example

a. Given a lot of parts to be tested by attributes. Lots having only $p_0 = .04$ fraction defective parts are to be accepted by the demonstration test plan 95% of the time (i.e., $\alpha = .05$). Lots having $p_1 = .10$ fraction defective are to be accepted 10% of the time (i.e., $\beta = .10$).

b. The decision points are:

$$\frac{1-\beta}{\alpha} = \frac{1-.10}{.05} = 18$$

$$\frac{\beta}{1-\alpha} = \frac{.10}{1-.05} = .105$$

c. In this example, if $(.10/.04)^f\,(.90/.96)^s$ is:

1) > 18, reject the lot.
2) < .105, accept the lot;
3) between .105 and 18, the test is continued.

3. Method — Example

Method

c. sampling as long as neither of these conditions arises.

d. The operating characteristic curve (i.e. the probability of acceptance as a function true fraction defective) can be roughly sketched from the following points:

p	Probability of Acceptance
0	1
p_0	$1-\alpha$
p_1	β
1	0
p'	Pa

where:

$$p' = \frac{\ln((1-p_1)/(1-p_0))}{\ln((1-p_1)/(1-p_0))-\ln(p_1/p_0)}$$

$$Pa = \frac{\ln((1-\beta)/\alpha}{\ln((1-\beta)/\alpha)-\ln(\beta/(1-\alpha))}$$

Example

d. The five points on the OC curve are as follows:

p	Prob. of Accept
0.00	1.00
.04	.95
.10	.10
1.00	0.00
.063	.56

The last point above is calculated as follows:

$\ln(.94)/(\ln(.94)-\ln(2.5))$

$= .063;$

$\ln(18)/(\ln(18)-\ln(.105))$

$= .56$

6.3 Variables Demonstration Tests

6.3.1 Introduction. Reliability demonstration tests conducted in industrial applications are virtually always constrained by time. It is almost never the case that a demonstration test is carried out by placing n items on test, and waiting until all (in the complete sample case) or $r < n$ (in the failure censored case) items have failed and recording their respective lifetimes. In practice, such sampling schemes are not used because the time necessary to complete the test is random, making it impossible for management to allocate the correct amount of time and resources to conduct the test. Instead, a time truncated test is appropriate (and often easier to administer) because an upper bound on the time to complete the test is known in advance of testing. Such tests were developed in MIL-STD-781C for the exponential distribution, and have been used almost exclusively in industry for electronic equipment.

Another aspect of sampling for reliability demonstration tests is replacement versus nonreplacement tests. That is, if n items are placed on life test initially, should failed items be replaced (or repaired to new working order) or not. Just as in the failure truncated case discussed above, the replacement life test presents a problem with respect to planning, since the ultimate number of items needed to complete the test is random and thus impossible to plan exactly in advance. Moreover, except in the exponential case, replacement tests are mathematically extremely difficult to develop in the time truncated case. Replacement tests are appropriate, however, when the item under test is a complete system, and "replacement" signifies "repair/restore to new working condition." Indeed, the MIL-STD-781C time truncated tests are replacement tests. Whenever the item to be tested is a complete, complex system in which the predominant failure modes are due to electronic (or other constant failure rate) equipments, then the MIL-STD-781C time truncated tests can be used. However, if the system is primarily composed of nonelectronic parts having increasing failure rates and the predominant failure modes are associated with these parts, then a replacement (by repair to new working order) test is out of the question, since in order to restore the system to new working order at each failure, each wear-out related part would have to be replaced with a new part whether failed or not.

In summary, when the exponential distribution is assumed, the time truncated tests presented in MIL-STD-781C are recommended in the replacement case. In the nonreplacement case, MIL-HDBK-108 (H 108) contains time truncated test plans for the exponential case. In view of the applicability of the exponential distribution to most nonelectronic parts in section 2 of this notebook, these documents should be adequate most of the time. When the exponential distribution is not justified, then a time truncated, nonreplacement demonstration test is recommended. Although they possess interesting statistical properties and are mathematically tractable, failure truncated demonstration tests (which include the complete sample case) are not desirable when time must be limited, and are not recommended here. For information concerning statistical inference for various life distributions under failure truncated sampling, refer to section 3 of this notebook, MIL-HDBK-108, or to Mann, et.al. (1974) or to Lawless (1982).

6.3.2 Time Truncated Demonstration Test Plans

6.3.2.1 Nonparametric Reliability Demonstration Test

1. When to use

This type of test is applicable to any situation in which reliability (i.e. probability of survival for a preselected time period), median life, or any quantile of the underlying life distribution is specified. This test procedure is valid no matter what form the underlying life distribution assumes (i.e. exponential, Weibull, Gamma, Lognormal, etc.) as long as it is of the continuous type.

2. Conditions for use

The user of this type of test plan must specify (or select from the table of test plans) the producer's risk (α), the consumer's risk

(β), the acceptable reliability (R_0), the unacceptable reliability (R_1), and the time (T) corresponding to the reliability values (i.e. R_0 is the acceptable probability of surviving the time T, while R_1 is the unacceptable probability of surviving the time T).

The test entails placing a predetermined fixed number of parts or equipments on test for T units of time, and recording the number items that fail before time T. Failed items are not replaced. The demonstration test is passed (i.e. items are judged to have the acceptable reliability R_0) if c or less items fail before time T, and the demonstration test is failed if c+1 or more items fail before time T. The value of c is predetermined by the user's specifications.

3. Method

a. Specify R_0, R_1, T, α, β or select them from the table of test plans, table 6.3.2.1.

b. Determine sample size n, and pass/fail number c as follows:

Choose the smallest c and the smallest n which satisfy the

inequalities:

$$1 - \alpha \leq \sum_{k=0}^{c} \binom{n}{k} (1-R_0)^k R_0^{\,n-k}$$

$$\beta \geq \sum_{k=0}^{c} \binom{n}{k} (1-R_1)^k R_1^{\,n-k}$$

This value of n is the sample size, and c is the decision criterion; that

Example

a. An axial blower must survive T=100 hours of continuous use with high probability. The acceptable reliability is

$R_0 = .95$

and unacceptable reliability is

$R_1 = .85$.

A producer's risk of no more than .10 and a consumer's risk of no more than .10 are acceptable.

b. From table 6.3.2.1, test plan 9A is appropriate. The sample size is n=60, and the test is passed if 5 or less failures occur before time T, and the test is failed if 6 or more failures occur before time T.

3\. Method | Example

b. is, the test is passed for c or less failures before time T, and the test is failed if c+1 or more failures occur before time T.

Alternatively, table 6.3.2.1 can be used to identify n and c.

c. Because the binomial distribution is discrete, the planned risks cannot be achieved exactly. The exact producer's and consumer's risks are given by one minus the first summation in b above, and the second summation in b above, respectively. Alternatively, if table 6.3.2.1 is used, the exact producer's and consumer's risks are given there. The test plans 1A-13A are based on planned values of .10 for both risks, and the test plans 1B-13B are based on planned values of .20 for both risks.

c. From table 6.3.2.1, test plan 9A, the exact risks are:

$\alpha = .079$
$\beta = .097$

d. Once a test plan is defined, it is often necessary to know what the probability of passing the test is as a function of true reliability, that is, the operating characteristic curve is needed. This curve gives the probability of passing the test (i.e. the probability of accepting the parts or equipments) for the entire range of possible values of the reliability,

d. Figure 6.3.2.9A is the operating characteristic curve for test plan 9A. As expected, when true reliability is $R_0 = .95$, the probability of acceptance is $1 - .079 = .921$, and when true reliability is $R_1 = .85$, the probability of acceptance is .097. If, for example, true reliability is .90, then the probability of acceptance is about .45.

3. Method | Example

d. not just at R_0 and R_1. The operating characteristic curve is defined by:

$$P\{\text{acceptance} \mid \text{reliability}=R\}$$

$$= \sum_{k=0}^{c} \binom{n}{k} (1-R)^k R^{n-k}$$

Figures 6.3.2.1A-6.3.2.13A and 6.3.2.1B-6.3.2.13B are the operating characteristic curves for test plans 1A-13A and 1B-13B, respectively.

TABLE 6.3.2.1. NONPARAMETRIC RELIABILITY DEMONSTRATION TEST PLANS

The planned producer's and consumer's risks are .10 for test plans 1A-13A, and .20 for test plans 1B-13B.

Plan	alpha	beta	RO	R1	n	ACCEPT equal or less	REJECT equal or more
1A	.095	.096	.50	.40	168	92	93
2A	.091	.099	.80	.70	127	31	32
3A	.087	.099	.85	.75	109	21	22
4A	.086	.099	.90	.80	86	12	13
5A	.096	.094	.91	.81	79	10	11
6A	.087	.093	.92	.82	77	9	10
7A	.095	.098	.93	.83	67	7	8
8A	.088	.096	.94	.84	64	6	7
9A	.079	.097	.95	.85	60	5	6
10A	.073	.092	.96	.86	56	4	5
11A	.063	.096	.97	.87	50	3	4
12A	.055	.097	.98	.88	43	2	3
13A	.045	.099	.99	.89	34	1	2
1B	.181	.194	.50	.40	77	42	43
2B	.197	.190	.80	.70	55	13	14
3B	.191	.183	.85	.75	49	9	10
4B	.190	.180	.90	.80	39	5	6
5B	.187	.199	.91	.81	34	4	5
6B	.157	.199	.92	.82	36	4	5
7B	.183	.183	.93	.83	32	3	4
8B	.145	.184	.94	.84	34	3	4
9B	.163	.187	.95	.85	28	2	3
10B	.117	.189	.96	.86	30	2	3
11B	.151	.180	.97	.87	23	1	2
12B	.083	.199	.98	.88	24	1	2
13B	.131	.196	.99	.89	14	0	1

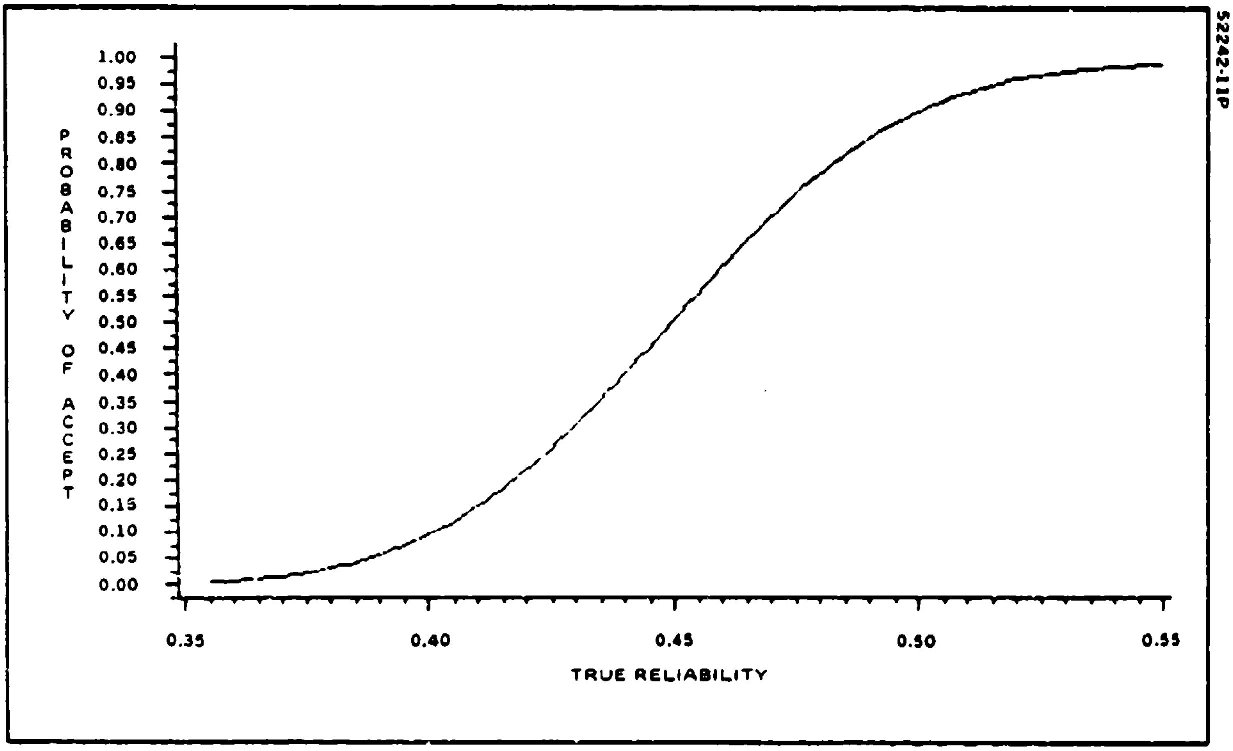

Figure 6.3.2.1A. Operating Characteristic Curve for Test Plan 1A

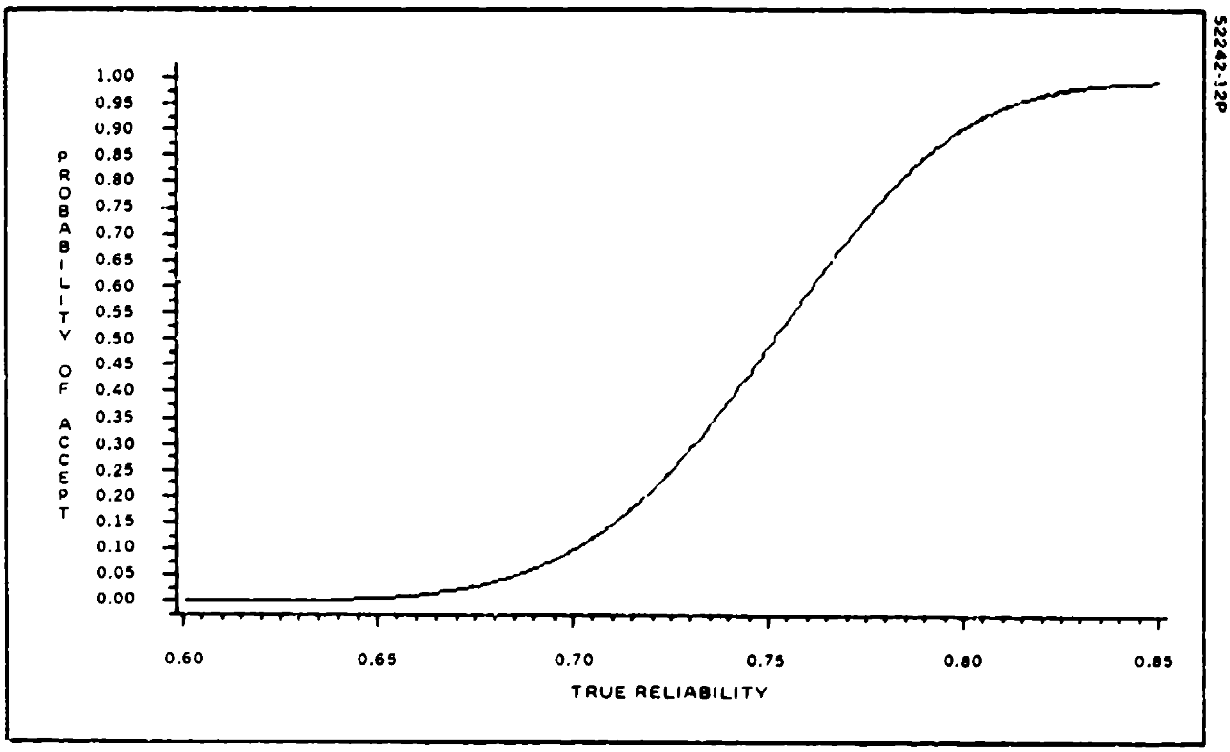

Figure 6.3.2.2A. Operating Characteristic Curve for Test Plan 2A

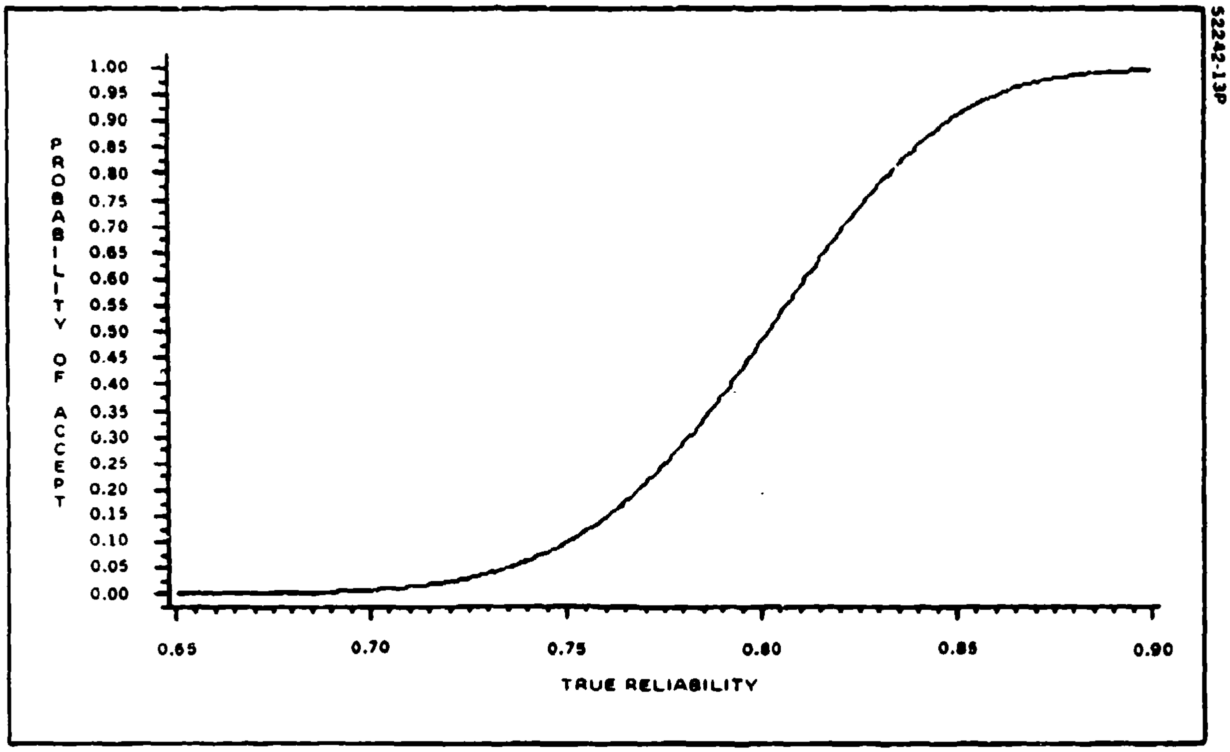

Figure 6.3.2.3A. Operating Characteristic Curve for Test Plan 3A

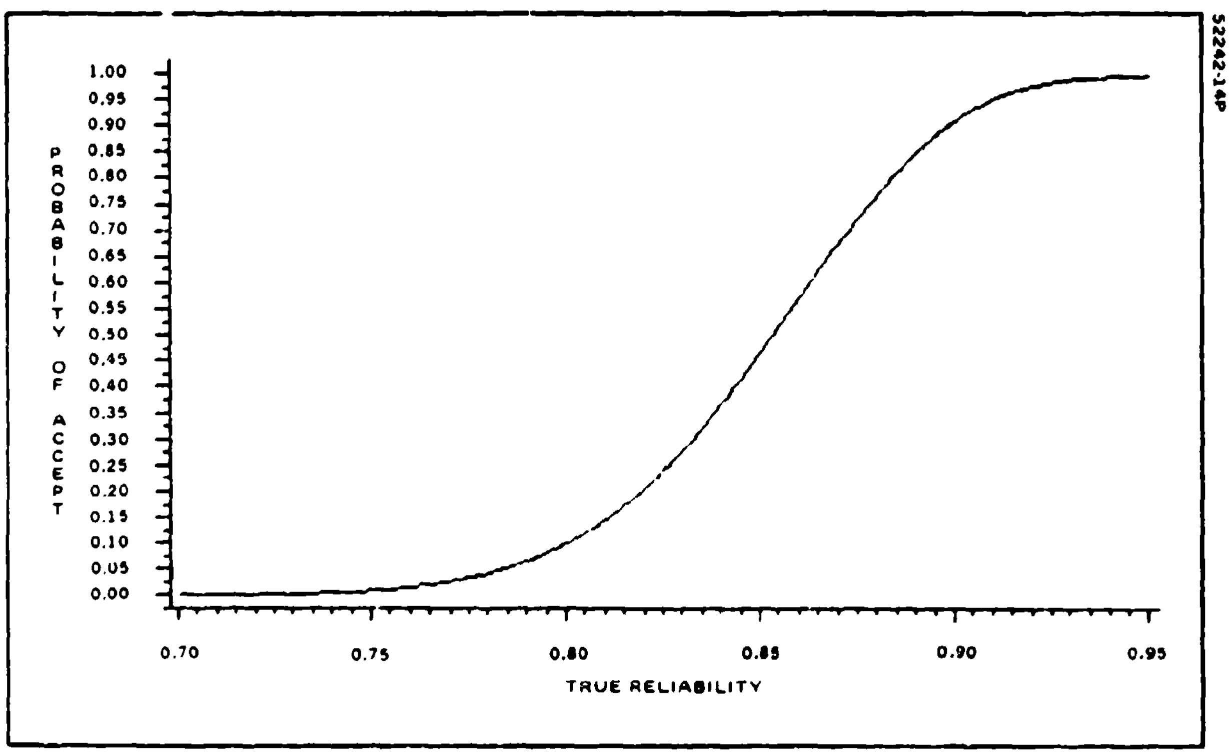

Figure 6.3.2.4A. Operating Characteristic Curve for Test Plan 4A

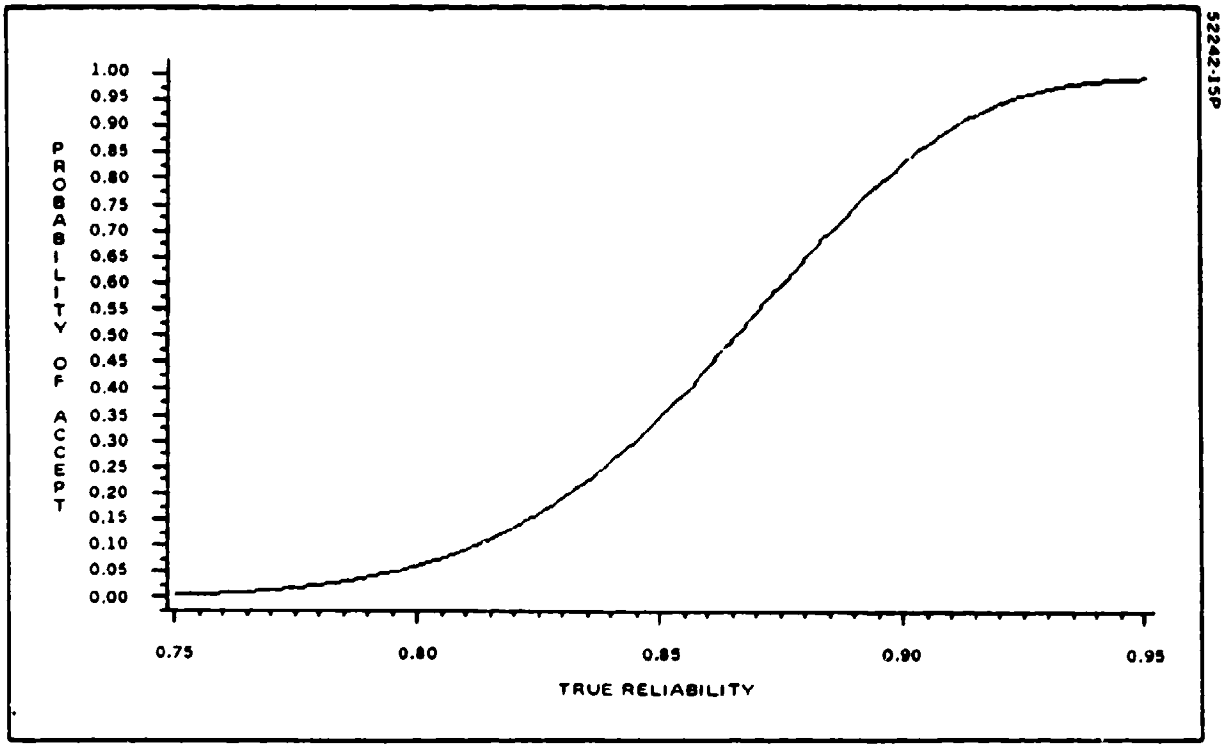

Figure 6.3.2.5A. Operating Characteristic Curve for Test Plan 5A

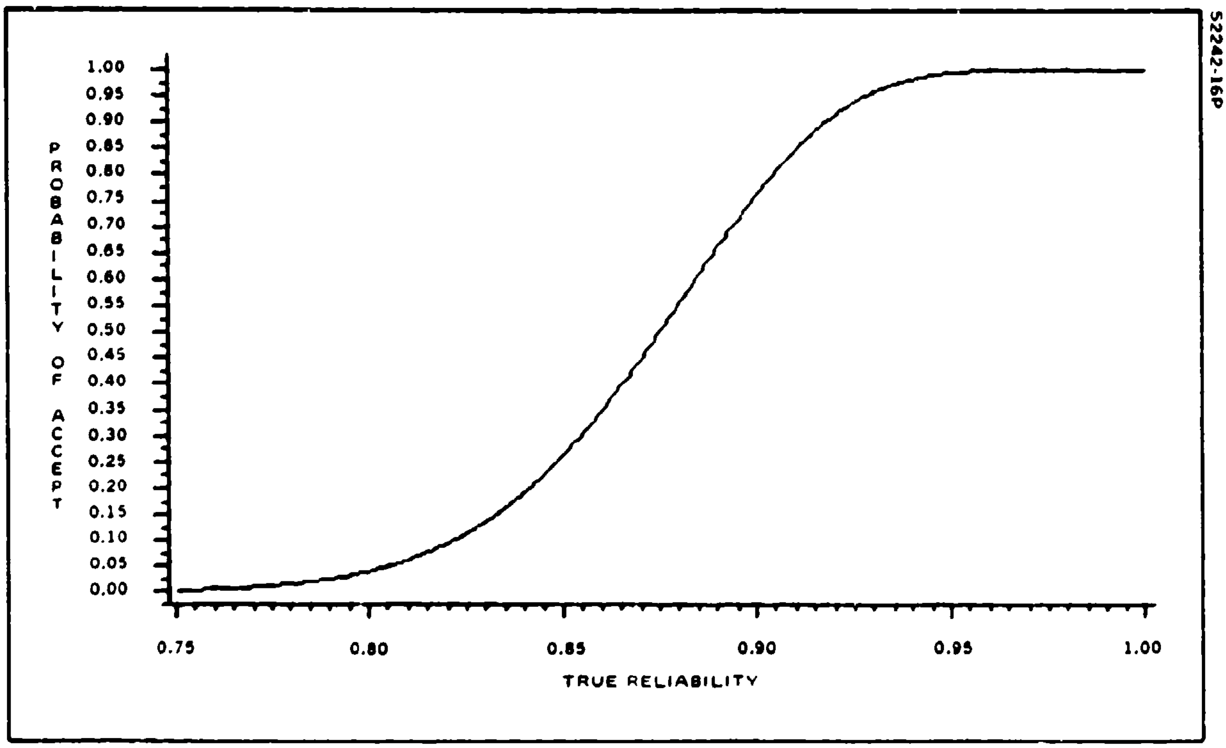

Figure 6.3.2.6A. Operating Characteristic Curve for Test Plan 6A

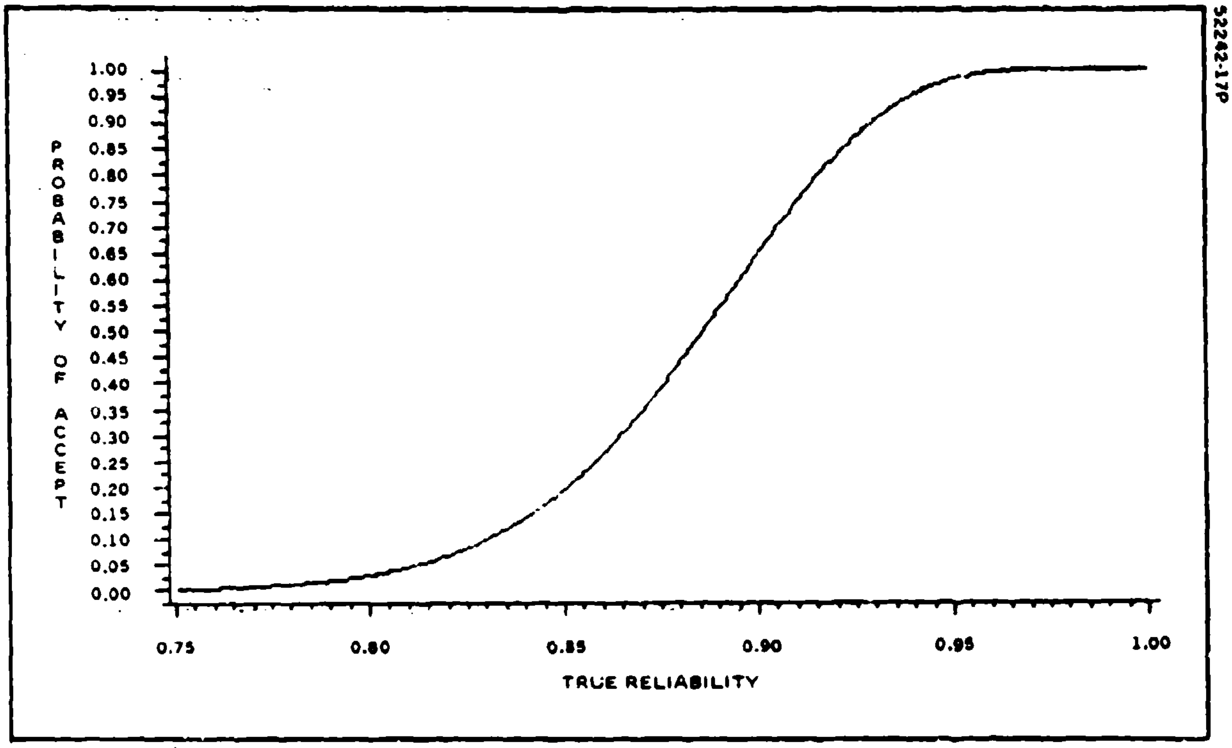

Figure 6.3.2.7A. Operating Characteristic Curve for Test Plan 7A

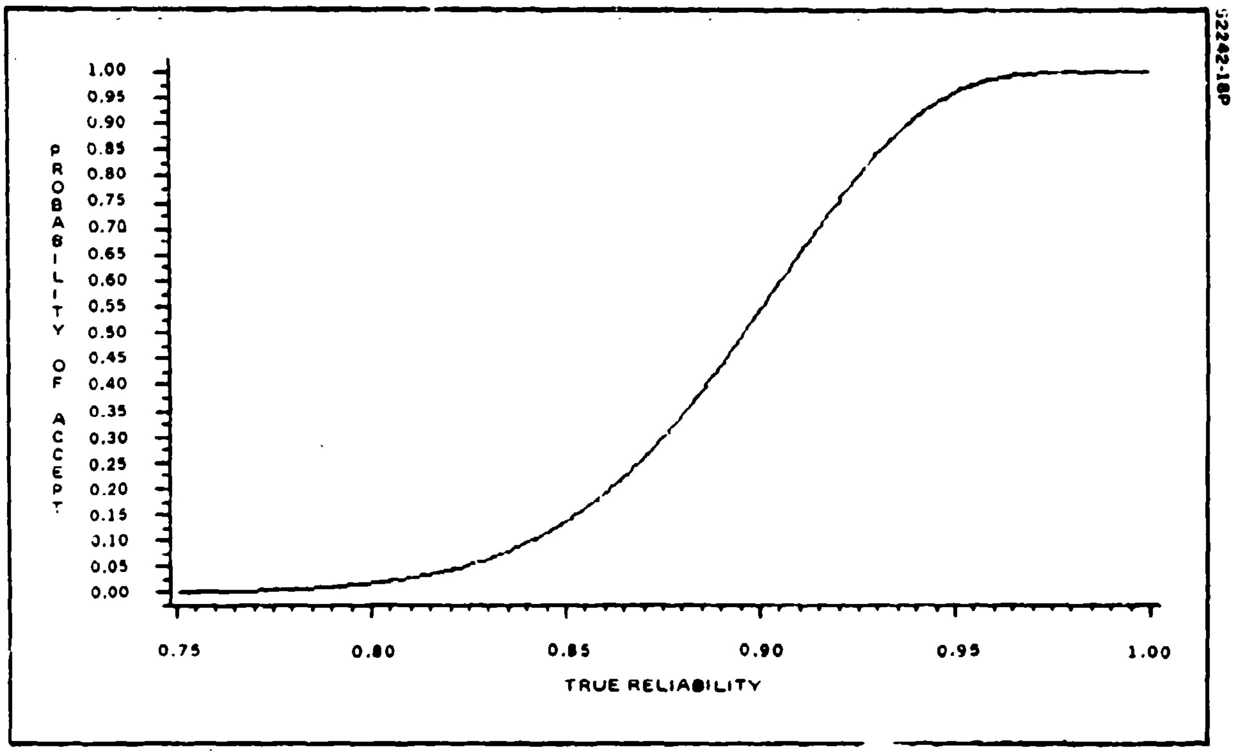

Figure 6.3.2.8A. Operating Characteristic Curve for Test Plan 8A

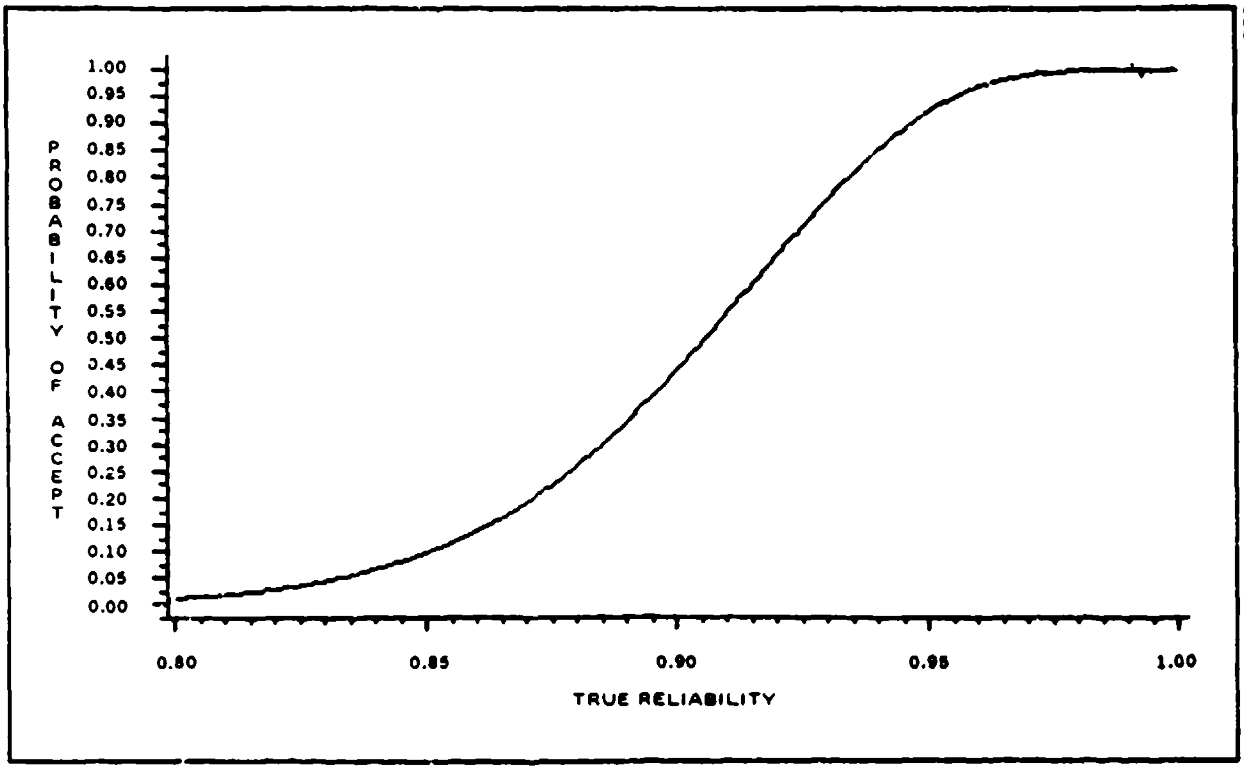

Figure 6.3.2.9A. Operating Characteristic Curve for Test Plan 9A

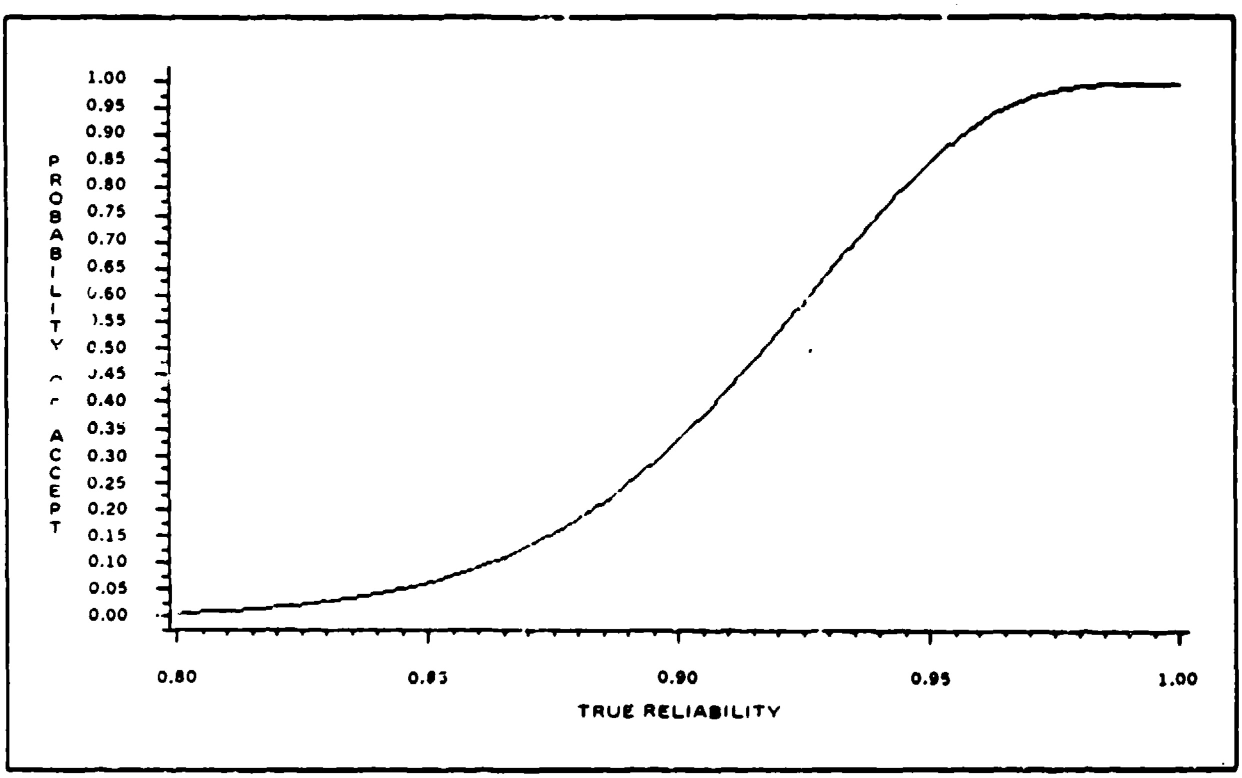

Figure 6.3.2.10A. Operating Characteristic Curve for Test Plan 10A

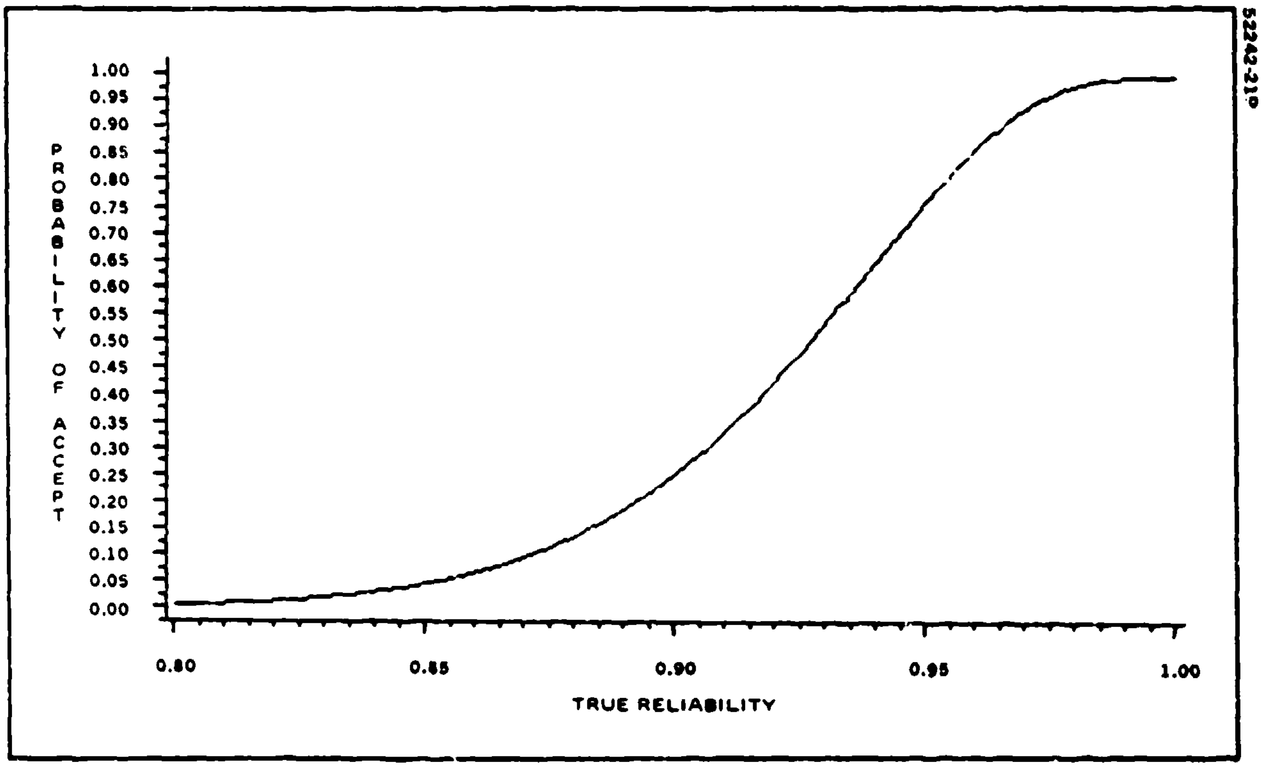

Figure 6.3.2.11A. Operating Characteristics Curve for Test Plan 11A

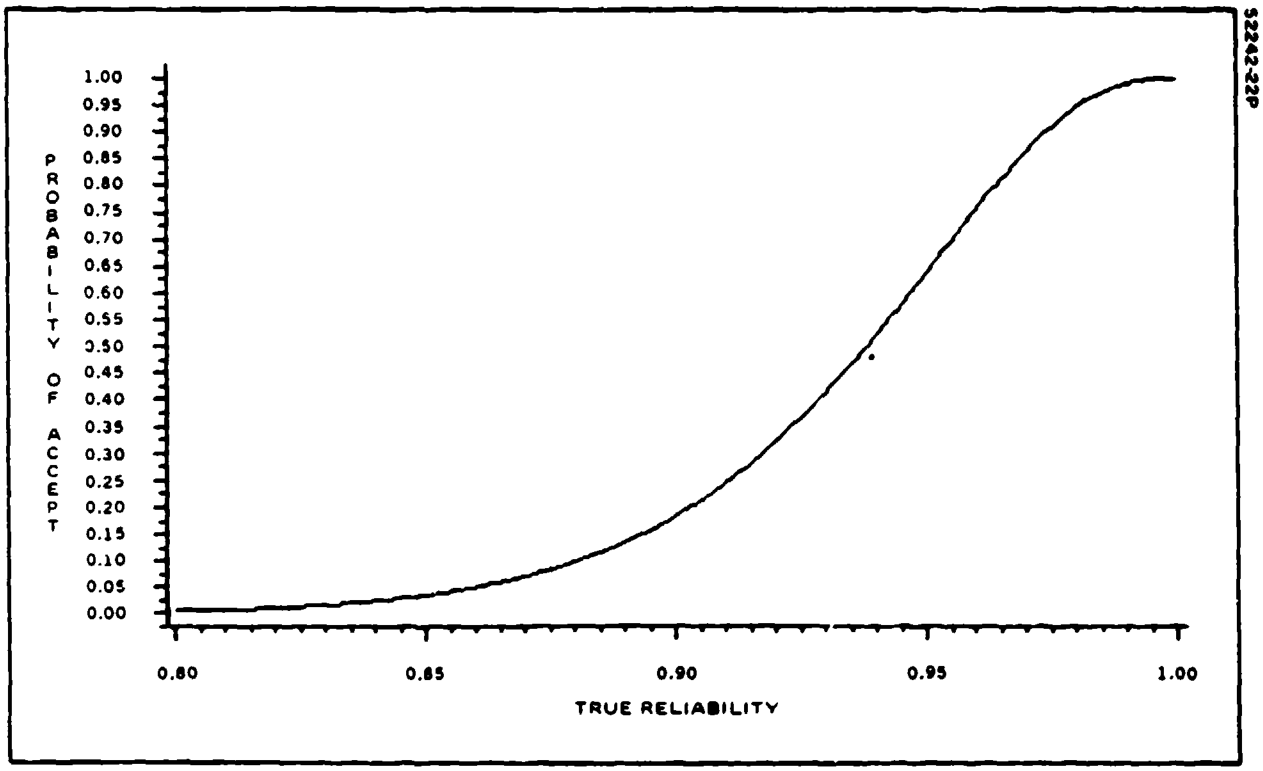

Figure 6.3.2.12A. Operating Characteristic Curve for Test Plan 12A

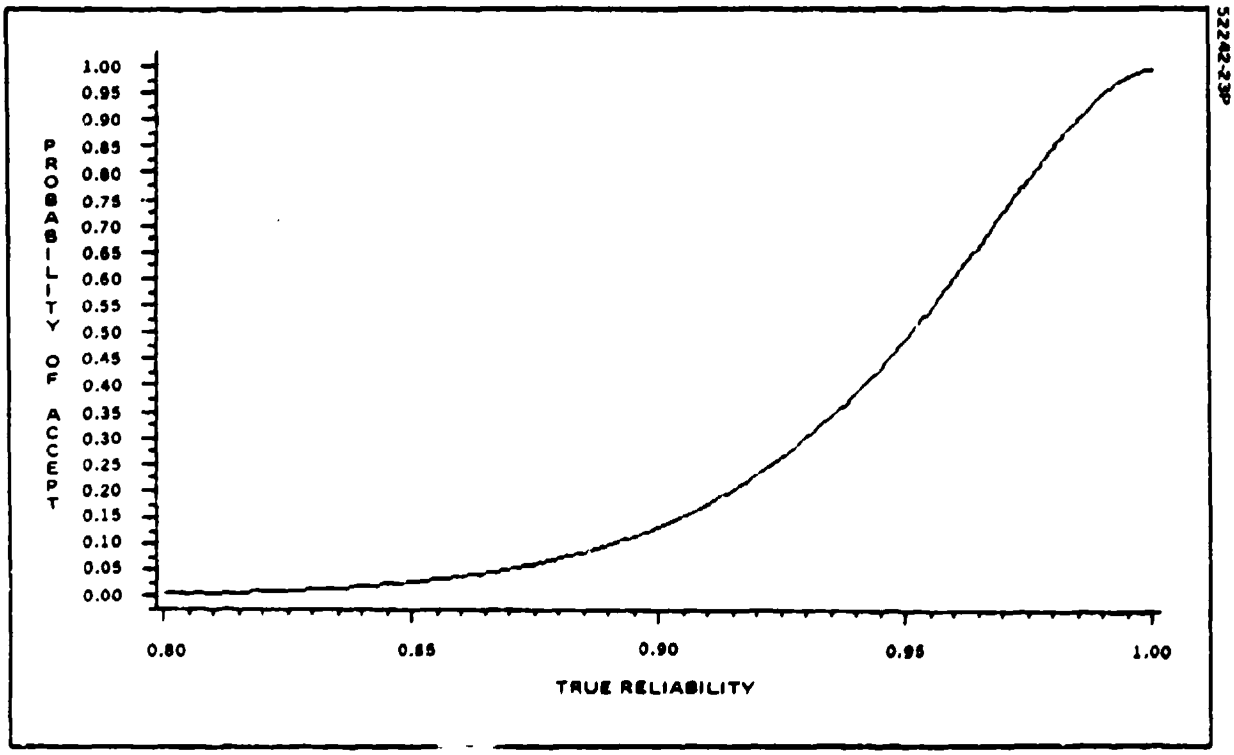

Figure 6.3.2.13A. Operating Characteristic Curve for Test Plan 13A

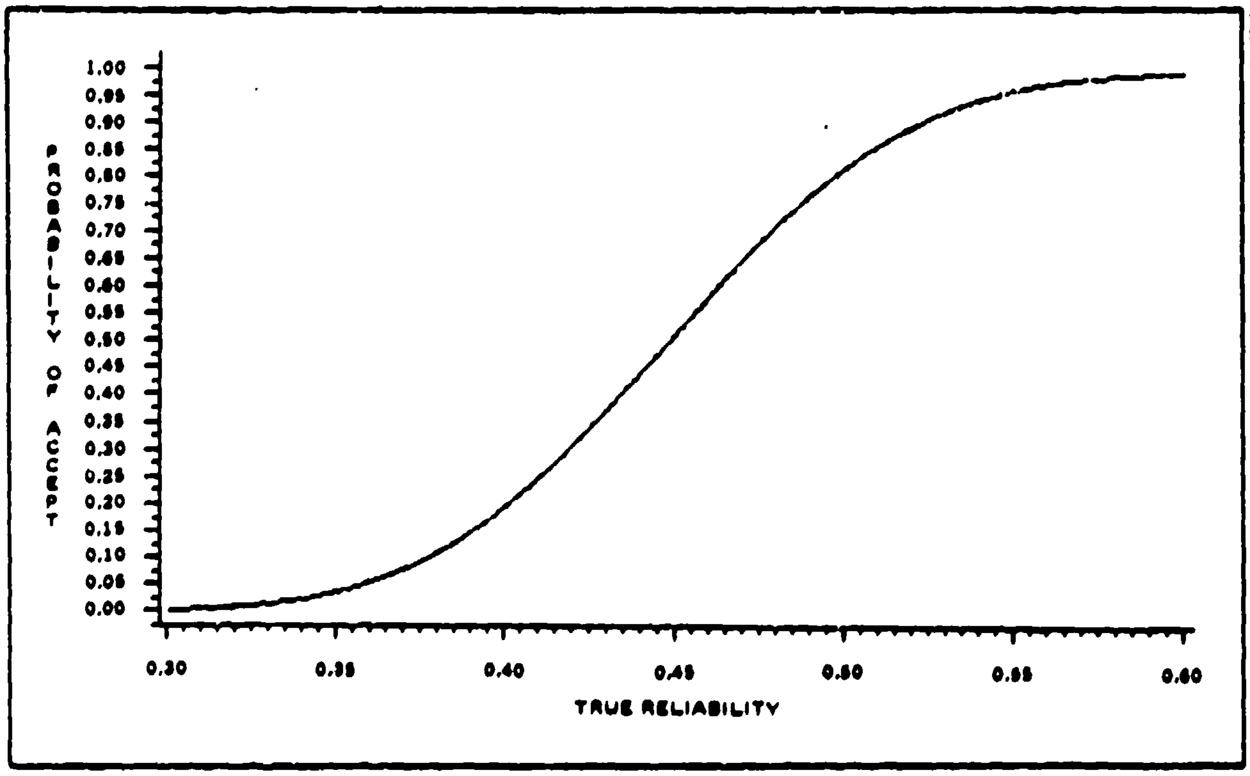

Figure 6.3.2.1B. Operating Characteristic Curve for Test Plan 1B

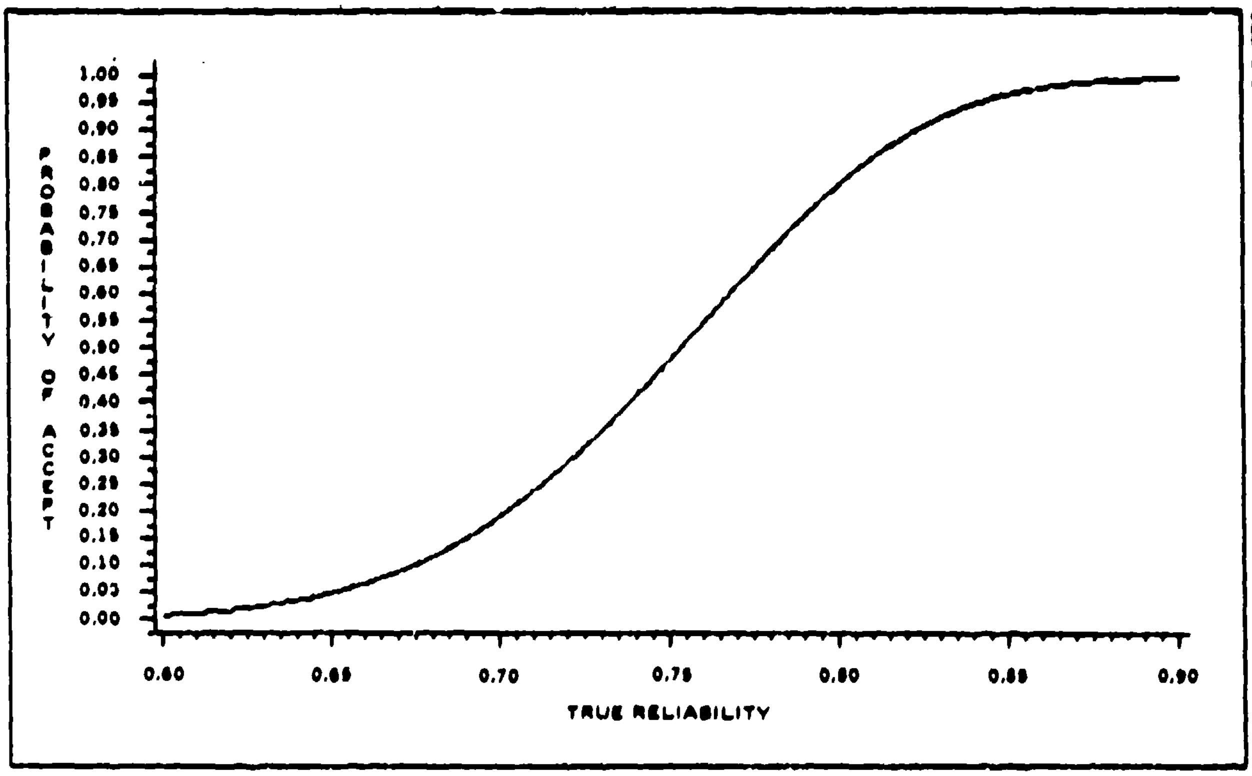

Figure 6.3.2.2B. Operating Characteristic Curve for Test Plan 2B

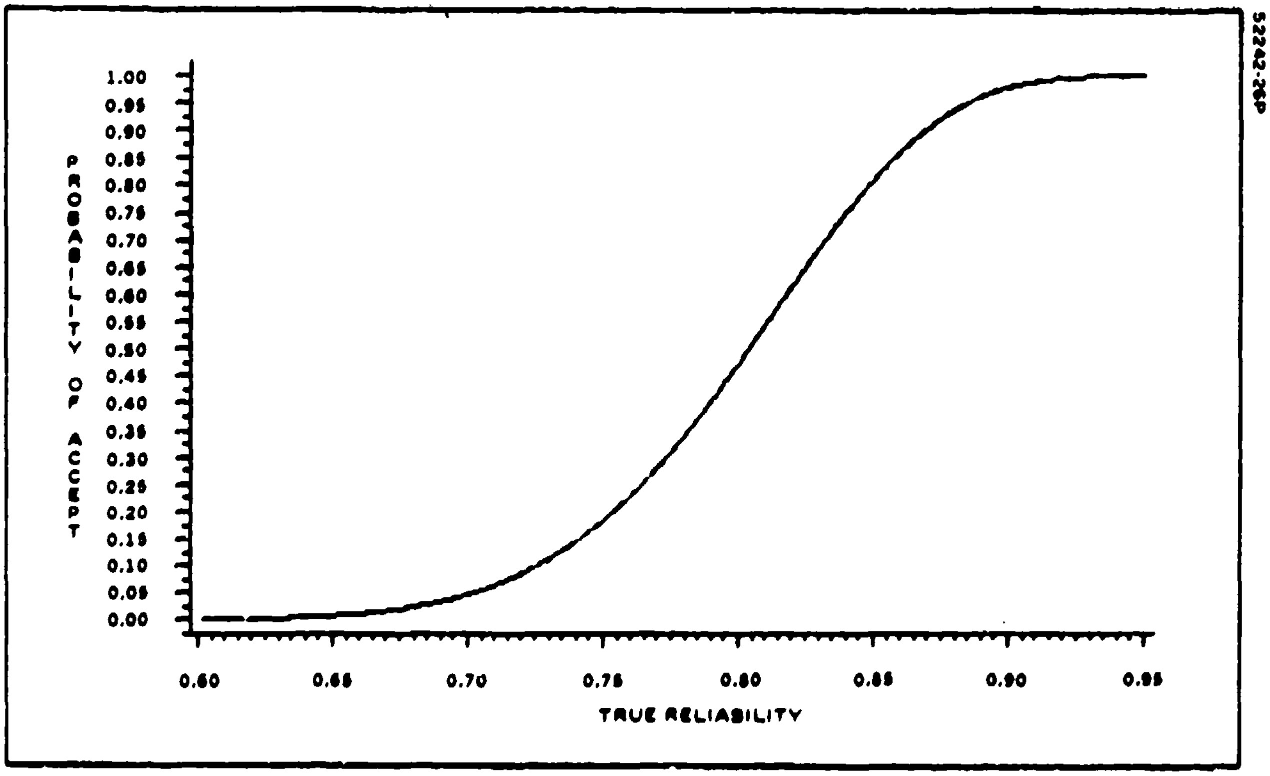

Figure 6.3.2.3B. Operating Characteristic Curve for Test Plan 3B

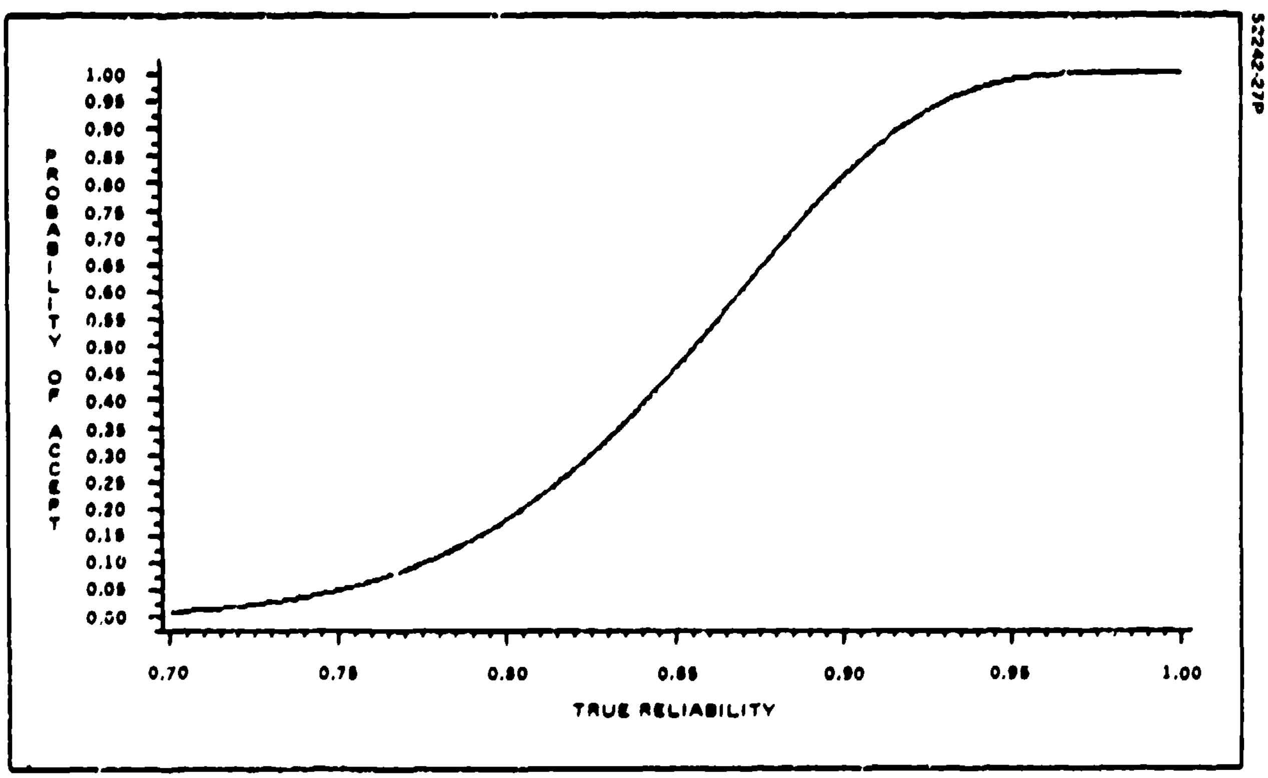

Figure 6.3.2.4B. Operating Characteristic Curve for Test Plan 4B

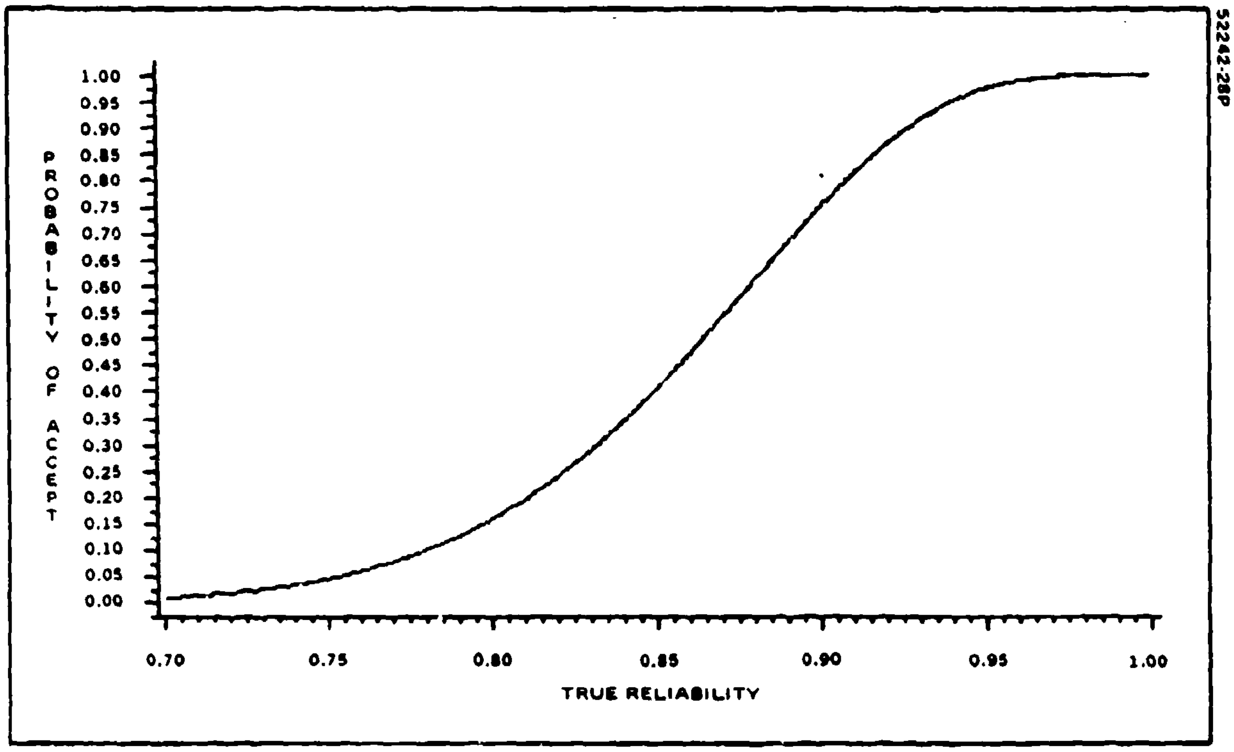

Figure 6.3.2.5B. Operating Characteristic Curve for Test Plan 5B

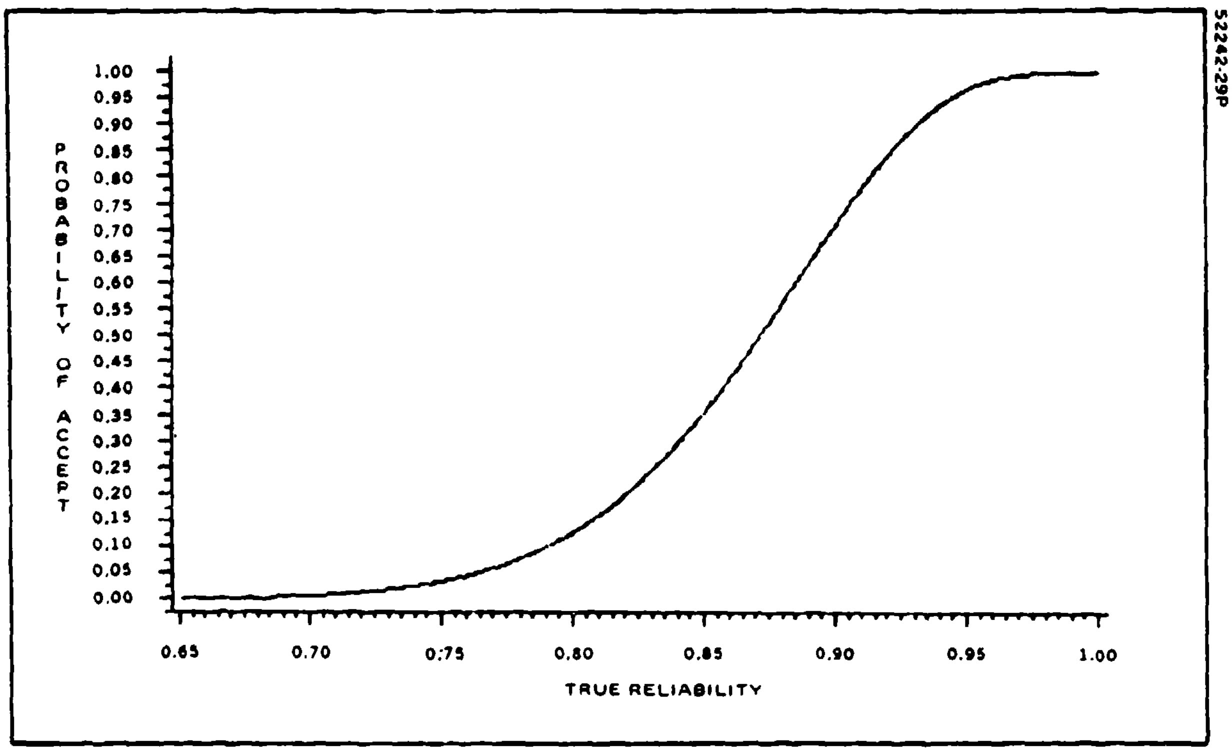

Figure 6.3.2.6B. Operating Characteristic Curve for Tes Plan 6B

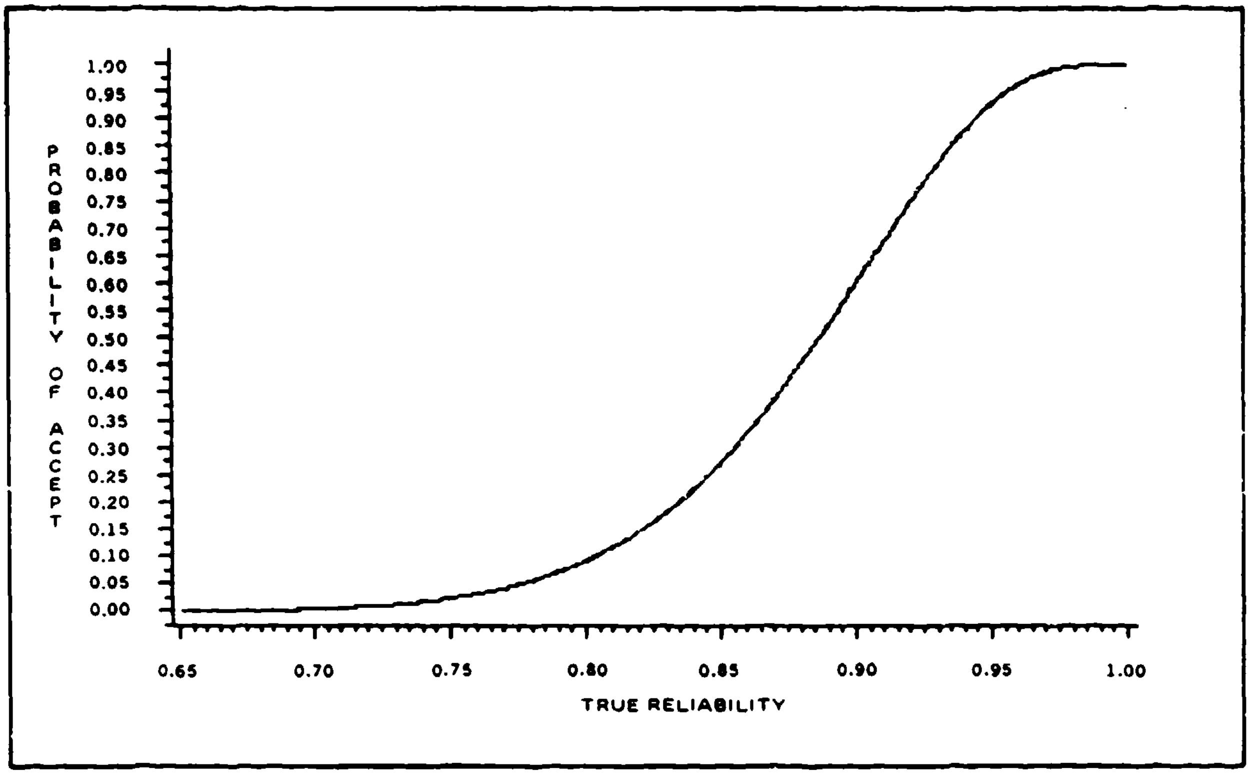

Figure 6.3.2.7B. Operating Characteristic Curve for Test Plan 7B

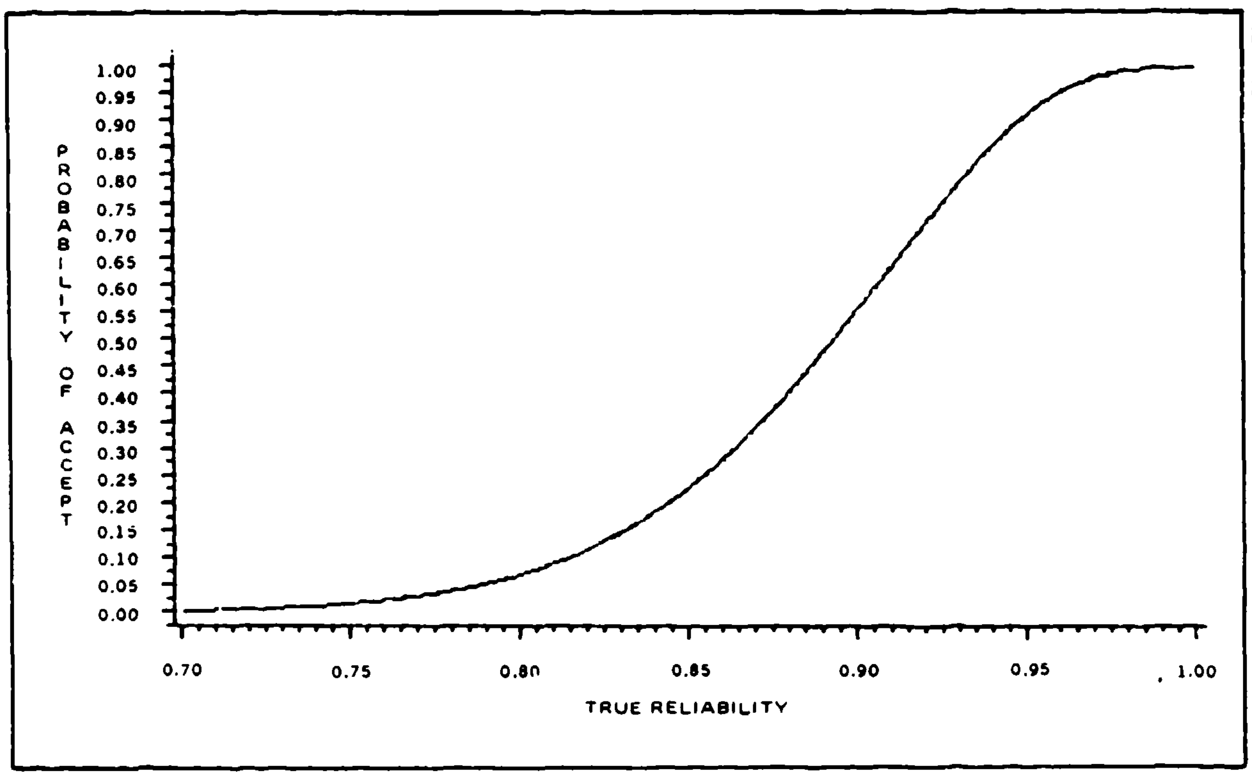

Figure 6.3.2.8B. Operating Characteristic Curve for Test Plan 8B

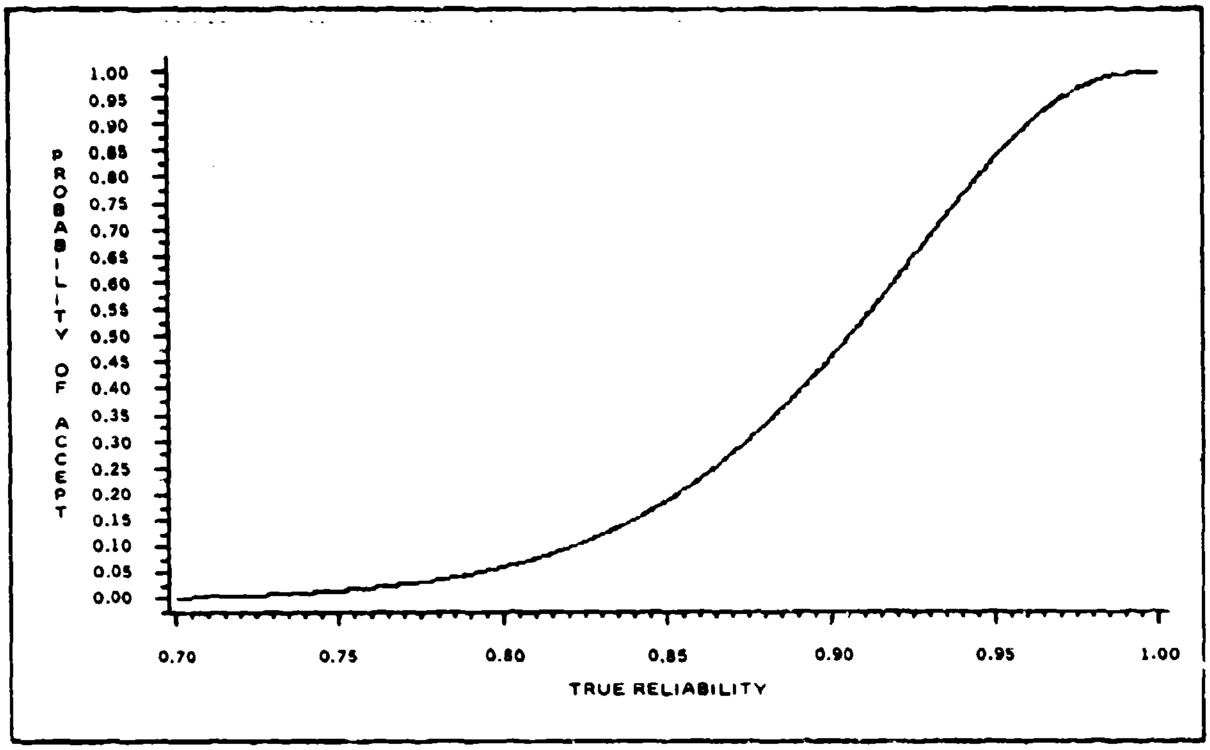

Figure 6.3.2.9B. Operating Characteristic Curve for Test Plan 9B

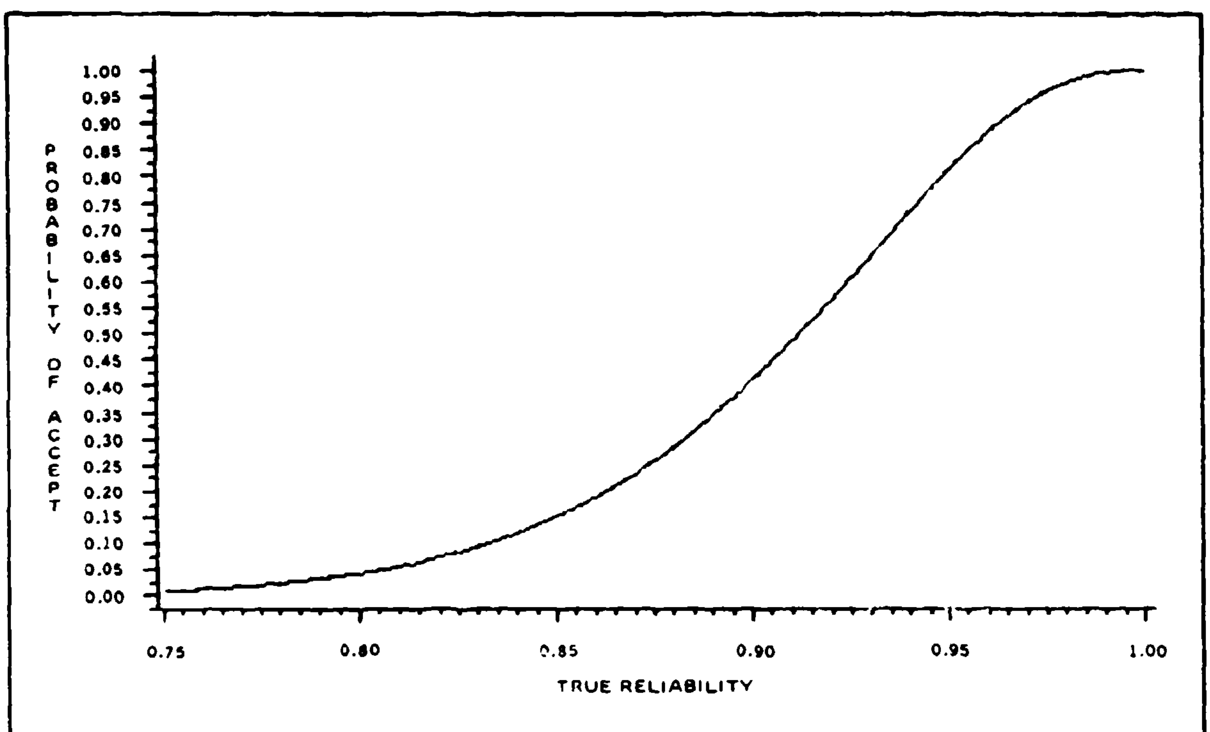

Figure 6.3.2.10B. Operating Characteristic Curve for Test Plan 10B

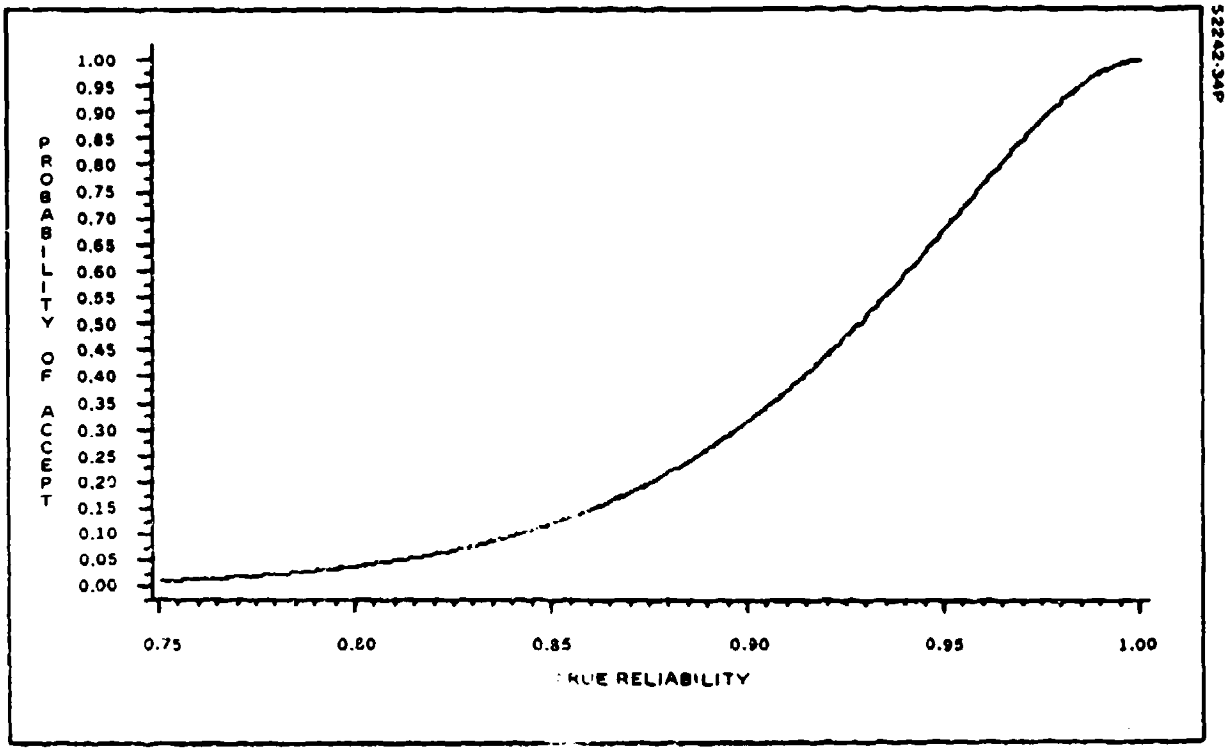

Figure 6.3.2.11B. Operating Characteristic Curve for Test Plan 11B

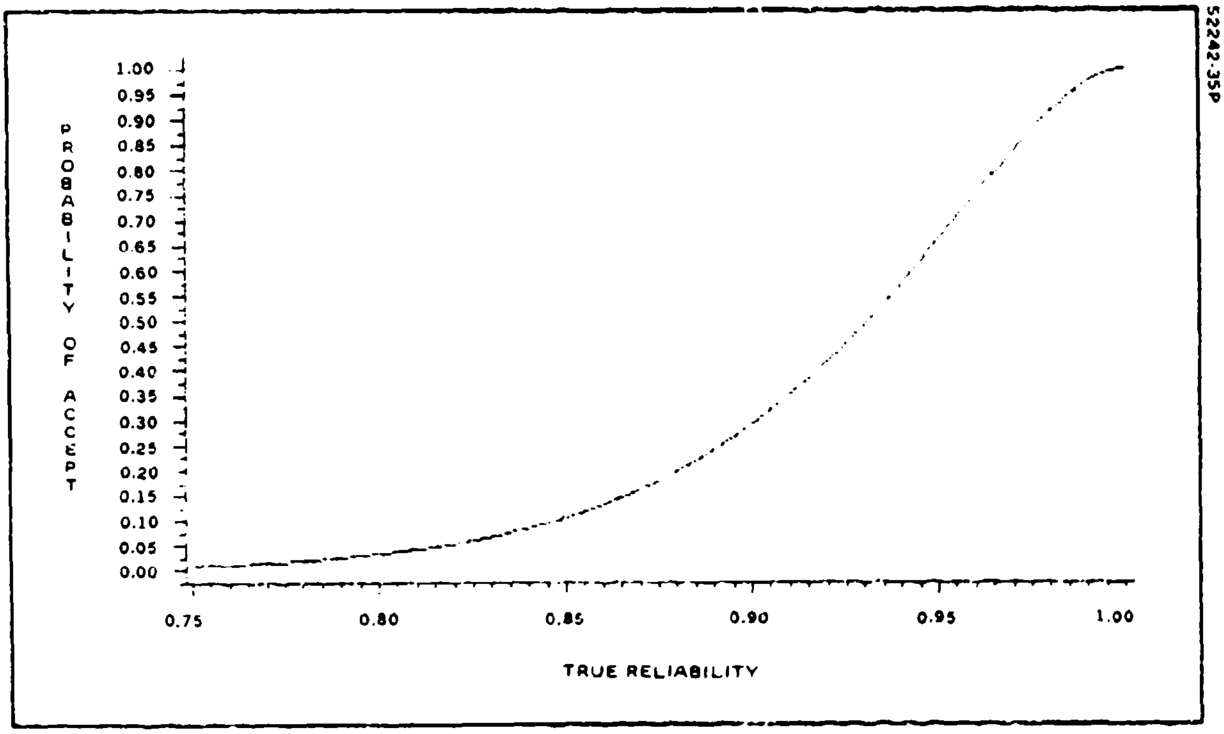

Figure 6.3.2.12B. Operating Characteristic Curve for Test Plan 12B

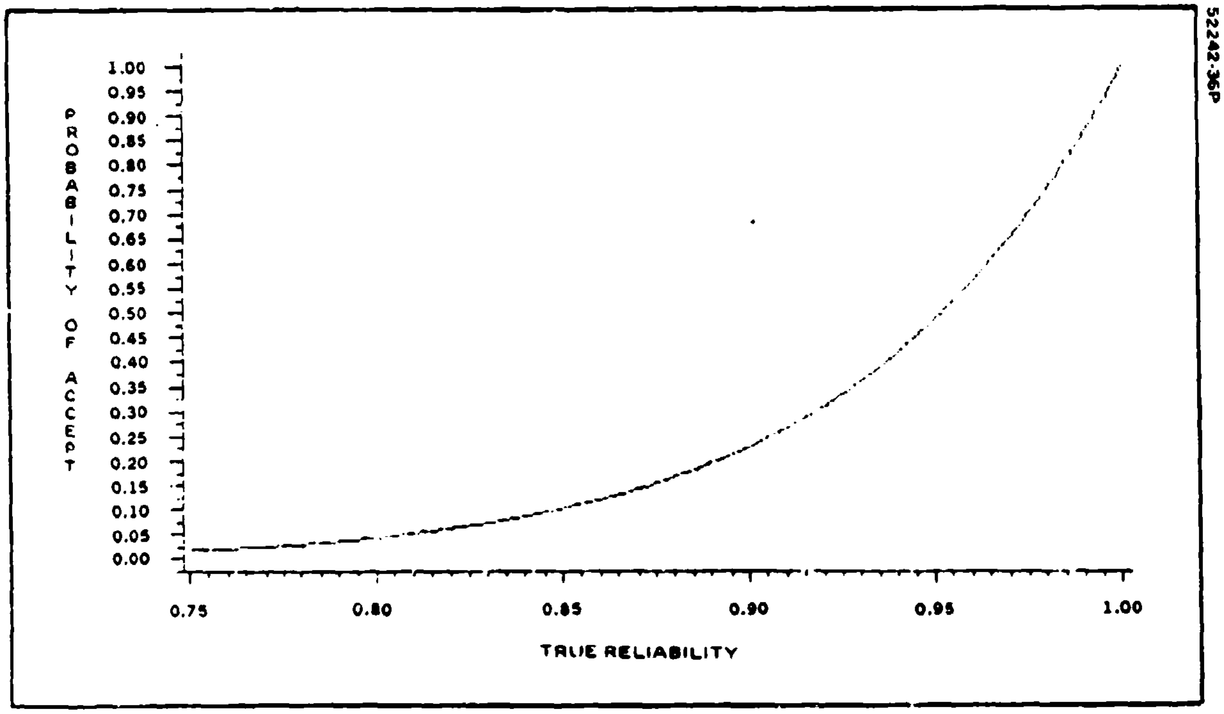

Figure 6.3.2.13B. Operating Characteristic Curve for Test Plan 13B

APPENDIX I
REFERENCES AND BIBLIOGRAPHY

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APPENDIX II

STATISTICAL TABLES

TABLE I. MEDIAN RANKS

sample size = n

failure rank = j

j	1	2	3	4	5	6	7	8	9	10
1	.5000	.2929	.2063	.1591	.1294	.1091	.0943	.0830	.0741	.0670
2		.7071	.5000	.3864	.3147	.2655	.2295	.2021	.1806	.1632
3			.7937	.6136	.5000	.4218	.3648	.3213	.2871	.2594
4				.8409	.6853	.5782	.5000	.4404	.3935	.3557
5					.8706	.7345	.6352	.5596	.5000	.4519
6						.8909	.7705	.6787	.6065	.5481
7							.9057	.7979	.7129	.6443
8								.9170	.8194	.7406
9									.9259	.8368
10										.9330

sample size = n
failure size = j

j	11	12	13	14	15	16	17	18	19	20
1	.0611	.0561	.0519	.0483	.0452	.0424	.0400	.0378	.0358	.0341
2	.1489	.1368	.1266	.1788	.1101	.1034	.0975	.0922	.0874	.0831
3	.2366	.2175	.2013	.1873	.1751	.1644	.1550	.1465	.1390	.1322
4	.3244	.2982	.2760	.2568	.2401	.2254	.2125	.2009	.1905	.1812
5	.4122	.3789	.3506	.3263	.3051	.2865	.2700	.2553	.2421	.2302
6	.5000	.4596	.4253	.3958	.3700	.3475	.3275	.3097	.2937	.2793
7	.5878	.5404	.5000	.4653	.4350	.4085	.3850	.3641	.3453	.3283
8	.6756	.6211	.5747	.5347	.5000	.4695	.4425	.4184	.3968	.3774
9	.7634	.7018	.6494	.6042	.5650	.5305	.5000	.4728	.4484	.4264
10	.8511	.7825	.7240	.6737	.6300	.5915	.5575	.5272	.5000	.4755
11	.9389	.8632	.7987	.7432	.6949	.6525	.6150	.5816	.5516	.5245
12		.9439	.8734	.8127	.7599	.7135	.6725	.6359	.6032	.5736
13			.9481	.8822	.8249	.7746	.7300	.6903	.6547	.6226
14				.9517	.8899	.8356	.7875	.7447	.7063	.6717
15					.9548	.8966	.8450	.7991	.7579	.7207
16						.9576	.9025	.8535	.8095	.7698
17							.9600	.9078	.8610	.8188
18								.9622	.9126	.8678
19									.9642	.9169
20										.9659

TABLE II. TABLE of 5% RANKS

sample size = n

j	1	2	3	4	5	6	7	8	9	10
1	.0500	.0253	.0170	.0127	.0102	.0085	.0074	.0065	.0057	.0051
2		.2236	.1354	.0976	.0764	.0629	.0534	.0468	.0410	.0368
3			.3684	.2486	.1893	.1532	.1287	.1111	.0978	.0873
4				.4729	.3426	.2713	.2253	.1929	.1688	.1500
5					.5493	.4182	.3413	.2892	.2514	.2224
6						.6070	.4793	.4003	.3449	.3035
7							.6518	.5293	.4504	.3934
8								.6877	.5709	.4931
9									.7169	.6058
10										.7411

sample size = n

j	11	12	13	14	15	16	17	18	19	20
1	.0047	.0043	.0040	.0037	.0034	.0032	.0030	.0029	.0028	.0026
2	.0333	.0307	.0281	.0263	.0245	.0227	.0216	.0205	.0194	.0183
3	.0800	.0719	.0665	.0611	.0574	.0536	.0499	.0476	.0452	.0429
4	.1363	.1245	.1127	.1047	.0967	.0910	.0854	.0797	.0761	.0725
5	.2007	.1824	.1671	.1527	.1424	.1321	.1247	.1173	.1099	.1051
6	.2713	.2465	.2255	.2082	.1909	.1786	.1664	.1575	.1485	.1396
7	.3498	.3152	.2883	.2652	.2459	.2267	.2128	.1990	.1887	.1785
8	.4356	.3909	.3548	.3263	.3016	.2805	.2601	.2449	.2298	.2183
9	.5299	.4727	.4274	.3904	.3608	.3350	.3131	.2912	.2749	.2586
10	.6356	.5619	.5054	.4600	.4226	.3922	.3542	.3429	.3201	.3029
11	.7616	.6613	.5899	.5343	.4893	.4517	.4208	.3927	.3703	.3469
12		.7791	.6837	.6416	.5602	.5156	.4781	.4460	.4196	.3957
13			.7942	.7033	.6366	.5834	.5395	.5022	.4711	.4434
14				.8074	.7206	.6562	.6044	.5611	.5242	.4932
15					.8190	.7360	.6738	.6233	.5809	.5444
16						.8274	.7475	.6871	.6379	.5964
17							.8358	.7589	.7005	.6525
18								.8441	.7704	.7138
19									.8525	.7818
20										.8609

TABLE III. TABLE OF 95% RANKS

sample size = n

j	1	2	3	4	5	6	7	8	9	10
1	.9500	.7764	.6316	.5271	.4507	.3930	.3482	.3123	.2831	.2589
2		.9747	.8646	.7514	.6574	.5818	.5207	.4707	.4291	.3942
3			.9830	.9024	.8107	.7287	.6587	.5997	.5496	.5069
4				.9873	.9236	.8468	.7747	.7108	.6551	.6056
5					.9898	.9371	.8713	.8071	.7486	.6965
6						.9915	.9466	.8889	.8312	.7776
7							.9926	.9532	.9032	.8500
8								.9935	.9590	.9127
9									.9943	.9632
10										.9949

sample size = n

j	11	12	13	14	15	16	17	18	19	20
1	.2384	.2209	.2058	.1926	.1810	.1726	.1642	.1559	.1475	.1391
2	.3644	.3387	.3163	.2967	.2794	.2640	.2525	.2411	.2296	.2182
3	.4701	.4381	.4101	.3854	.3634	.3438	.3262	.3129	.2995	.2862
4	.5644	.5273	.4946	.4657	.4398	.4166	.3956	.3767	.3621	.3475
5	.6502	.6091	.5726	.5400	.5107	.4844	.4605	.4389	.4191	.4036
6	.7287	.6848	.6452	.6096	.5774	.5483	.5219	.4978	.4758	.4556
7	.7993	.7535	.7117	.6737	.6392	.6078	.5792	.5540	.5289	.5068
8	.8637	.8176	.7745	.7348	.6984	.6650	.6458	.6063	.5804	.5566
9	.9200	.8755	.8329	.7918	.7541	.7195	.6869	.6571	.6297	.6043
10	.9667	.9281	.8873	.8473	.8091	.7733	.7399	.7088	.6799	.6531
11	.9953	.9693	.9335	.8953	.8576	.8214	.7872	.7551	.7251	.6971
12		.9957	.9719	.9389	.9033	.8679	.8336	.8010	.7702	.7413
13			.9960	.9737	.9426	.9090	.8753	.8425	.8113	.7818
14				.9963	.9755	.9464	.9146	.8827	.8525	.8215
15					.9966	.9773	.9501	.9203	.8901	.8604
16						.9968	.9784	.9534	.9239	.8949
17							.9970	.9795	.9548	.9275
18								.9971	.9806	.9571
19									.9972	.9817
20										.9974

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION

S/X̄	.5th	1st	2.5th	5th
.01	.974522	.976956	.980542	.983637
.02	.949602	.954342	.96137	.967447
.03	.925235	.932184	.942484	.951434
.04	.901413	.91045	.923886	.9356
.05	.87813	.889146	.905574	.919946
.06	.855381	.86827	.887551	.904476
.07	.833158	.847817	.869815	.889191
.08	.811453	.827785	.852368	.874093
.09	.790261	.808169	.835208	.859184
.1	.769574	.788966	.818334	.844465
.11	.749384	.77017	.801747	.829938
.12	.729683	.751778	.785445	.815604
.13	.710465	.733785	.769428	.801464
.14	.69172	.716186	.753693	.787519
.15	.673442	.698976	.73824	.773769
.16	.655622	.68215	.723067	.760215
.17	.638252	.665703	.708172	.746857
.18	.621324	.649629	.693553	.733697
.19	.60483	.6333924	.679208	.720732
.2	.588761	.618581	.665135	.707965
.21	.57311	.603596	.651331	.695394
.22	.557868	.588961	.637794	.683019
.23	.543026	.574672	.624522	.670839
.24	.528577	.560723	.611511	.658855
.25	.514512	.547108	.598759	.647065
.26	.500823	.533821	.586263	.635468
.27	.487502	.520856	.57402	.624063
.28	.474541	.508207	.562026	.61285
.29	.461931	.495868	.550279	.601827
.3	.449665	.483834	.538775	.590992
.31	.437735	.472097	.527512	.580345
.32	.426132	.460653	.516484	.569884
.33	.414849	.449495	.50569	.559607
.34	.403879	.438618	.495125	.549513
.35	.393213	.428015	.484787	.539599
.36	.382844	.417681	.47467	.529865
.37	.372764	.407609	.464773	.520308
.38	.362967	.397795	.455091	.510926
.39	.353445	.388232	.445621	.501718
.4	.344191	.378914	.436358	.49268
.41	.335198	.369837	.4273	.483812

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\bar{X}$	.5th	1st	2.5th	5th
.42	.326459	.360994	.418442	.475111
.43	.317968	.35238	.409782	.466575
.44	.309717	.34399	.401315	.458201
.45	.301701	.335818	.393037	.449987
.46	.293912	.327858	.384946	.441932
.47	.286346	.320107	.377036	.434032
.48	.278994	.312558	.369306	.426286
.49	.271853	.305208	.361751	.418691
.5	.264915	.298049	.354368	.411244

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\overline{X}$	10th	20th	30th	40th
.01	.987217	.991569	.99472	.997419
.02	.974502	.983113	.989369	.994747
.03	.961858	.9764634	.983951	.991983
.04	.94929	.966135	.978468	.98913
.05	.936799	.957621	.972921	.986188
.06	.92439	.949092	.967313	.983159
.07	.912066	.940554	.961647	.980044
.08	.899829	.932009	.955925	.976846
.09	.887682	.92346	.95015	.973566
.1	.87563	.914911	.944325	.970205
.11	.863673	.906364	.938451	.966766
.12	.851815	.897823	.932531	.96325
.13	.840058	.889289	.926569	.959659
.14	.828405	.880768	.920567	.955995
.15	.816858	.87226	.914527	.95226
.16	.805419	.86377	.908451	.948456
.17	.794089	.8553	.902344	.944586
.18	.782872	.846852	.896207	.940651
.19	.771768	.83843	.890042	.936653
.2	.760779	.830035	.883853	.932594
.21	.749907	.821671	.877642	.928478
.22	.739154	.81334	.871412	.924305
.23	.728519	.805044	.865164	.920079
.24	.718006	.796786	.858903	.915801
.25	.707614	.788568	.852629	.911473
.26	.697344	.780391	.846345	.907099
.27	.687198	.772259	.840055	.902679
.28	.677176	.764173	.83376	.898217
.29	.667278	.756135	.827462	.893714
.3	.657506	.748147	.821164	.889173
.31	.647859	.740211	.814868	.884596
.32	.638337	.732328	.808576	.879986
.33	.628942	.7245	.80229	.875343
.34	.619673	.716728	.796013	.870671
.35	.61053	.709015	.789746	.865972
.36	.601512	.70136	.783492	.861247
.37	.59262	.693767	.777251	.856499
.38	.583854	.686235	.771027	.851729
.39	.575213	.678766	.76482	.846941
.4	.566696	.671362	.758633	.842135
.41	.558304	.664022	.752467	.837314

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\overline{X}$	.5th	1st	2.5th	5th
.42	.550034	.656748	.746324	.83248
.43	.541888	.649541	.740205	.827634
.44	.533864	.642401	.734112	.822779
.45	.525961	.635329	.728046	.817916
.46	.518179	.628327	.722009	.813046
.47	.510517	.621393	.716002	.808173
.48	.502973	.61453	.710026	.803296
.49	.495547	.607736	.704083	.798418
.5	.488238	.601014	.698173	.793541

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\bar{X}$	60th	70th	80th	90th
.01	1.00249	1.00521	1.0084	1.01285
.02	1.00488	1.01034	1.01677	1.02575
.03	1.00717	1.0154	1.0251	1.03872
.04	1.00937	1.02037	1.0334	1.05174
.05	1.01148	1.02527	1.4165	1.0648
.06	1.01348	1.03008	1.04986	1.07791
.07	1.01539	1.03481	1.05802	1.09107
.08	1.01719	1.03945	1.06613	1.10425
.09	1.0189	1.04401	1.07418	1.11748
.1	1.0205	1.04847	1.08218	1.13073
.11	1.02201	1.05285	1.09012	1.144
.12	1.02341	1.05713	1.09799	1.1573
.13	1.02472	1.06131	1.1058	1.17061
.14	1.02592	1.0654	1.11355	1.18393
.15	1.02702	1.0694	1.12122	1.19726
.16	1.02803	1.0733	1.12882	1.2106
.17	1.02893	1.0771	1.13634	1.22393
.18	1.02973	1.0808	1.14378	1.23726
.19	1.03043	1.08439	1.15115	1.25058
.2	1.03104	1.08789	1.15843	1.26389
.21	1.03154	1.09129	1.16563	1.27717
.22	1.03195	1.09458	1.17274	1.29044
.23	1.03226	1.09778	1.17976	1.30368
.24	1.03247	1.10087	1.18669	1.31689
.25	1.03259	1.10385	1.19353	1.33007
.26	1.03261	1.10673	1.20027	1.34321
.27	1.03254	1.10951	1.20692	1.35631
.28	1.03238	1.11219	1.21347	1.36936
.29	1.03212	1.11476	1.21992	1.38237
.3	1.03178	1.11723	1.22627	1.39532
.31	1.03135	1.1196	1.23252	1.40822
.32	1.03083	1.12186	1.23867	1.42105
.33	1.03022	1.12402	1.24471	1.43383
.34	1.02953	1.12608	1.25065	1.44653
.35	1.02875	1.12804	1.25649	1.45917
.36	1.02789	1.1299	1.26222	1.47174
.37	1.02695	1.13166	1.26784	1.48423
.38	1.02594	1.13332	1.27335	1.49664
.39	1.02484	1.13488	1.27876	1.50897
.4	1.02367	1.13634	1.28406	1.52122
.41	1.02242	1.13771	1.28925	1.53338

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

s/$\bar{X}$	60th	70th	80th	90th
.42	1.02111	1.13898	1.29433	1.54545
.43	1.01972	1.14016	1.29931	1.55743
.44	1.01826	1.14124	1.30417	1.56931
.45	1.1673	1.14224	1.30893	1.5811
.46	1.01514	1.14314	1.31358	1.5928
.47	1.01348	1.14395	1.31811	1.60439
.48	1.01176	1.14467	1.32255	1.61588
.49	1.00998	1.1453	1.32687	1.62726
.5	1.00814	1.14585	1.33108	1.63854

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	95th	97.5th	99th	99.5th
.01	1.01653	1.10974	1.02348	1.02604
.02	1.03323	1.03977	1.04741	1.05265
.03	1.0501	1.06007	1.07178	1.07983
.04	1.06713	1.08066	1.0966	1.1076
.05	1.08431	1.10152	1.12187	1.13594
.06	1.10165	1.12265	1.14758	1.16488
.07	1.11913	1.14406	1.17375	1.1944
.08	1.13677	1.16574	1.20036	1.22452
.09	1.15454	1.18769	1.22742	1.25524
.1	1.17246	1.20989	1.25493	1.28655
.11	1.1905	1.23236	1.28289	1.31848
.12	1.20868	1.25509	1.3113	1.351
.13	1.22698	1.27807	1.34015	1.38414
.14	1.2454	1.30129	1.36944	1.41788
.15	1.26394	1.32476	1.39918	1.45223
.16	1.28258	1.34848	1.42936	1.4872
.17	1.30133	1.37242	1.45998	1.52277
.18	1.32019	1.3966	1.49103	1.55895
.19	1.33913	1.421	1.52251	1.59575
.2	1.35817	1.44563	1.55442	1.63315
.21	1.37729	1.47047	1.58676	1.67117
.22	1.3965	1.49552	1.61952	1.70978
.23	1.41577	1.52077	1.65269	1.74901
.24	1.43512	1.54623	1.68628	1.78883
.25	1.45453	1.57188	1.72027	1.82926
.26	1.474	1.59771	1.75467	1.87028
.27	1.49352	1.62373	1.78946	1.91189
.28	1.51309	1.64992	1.82465	1.9541
.29	1.53271	1.67628	1.86022	1.99688
.3	1.55236	1.70281	1.89617	2.04025
.31	1.57204	1.72949	1.93249	2.08419
.32	1.59175	1.75632	1.96918	2.12871
.33	1.61148	1.78329	2.00624	2.17379
.34	1.63122	1.81041	2.04364	2.21942
.35	1.65098	1.83765	2.08139	2.26561
.36	1.67074	1.86502	2.11946	2.31235
.37	1.69051	1.8925	2.15791	2.35962
.38	1.71027	1.9201	2.19666	2.40743
.39	1.73002	1.9478	2.23572	2.45577
.4	1.74975	1.9756	2.2751	2.50462
.41	1.76947	2.00349	2.31478	2.55398

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	95th	97.5th	99th	99.5th
.42	1.78916	2.03146	2.35475	2.60385
.43	1.80883	2.05952	2.395	2.6542
.44	1.82846	2.08764	2.43554	2.70505
.45	1.84805	2.11583	2.47634	2.75637
.46	1.86761	2.14408	2.51741	2.80816
.47	1.88711	2.17238	2.55873	2.86041
.48	1.90657	2.20073	2.60029	2.91311
.49	1.92597	2.22912	2.64209	2.96626
.5	1.94531	2.25754	2.68412	3.01983

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\overline{X}$	.5th	1st	2.5th	5th
.5	.264915	.298049	.354368	.411244
.51	.258175	.291079	.347152	.403944
.52	.251628	.284292	.340102	.396788
.53	.245268	.277683	.333213	.389774
.54	.239089	.271248	.326481	.382898
.55	.233086	.264983	.319904	.37616
.56	.227256	.258882	.313478	.369557
.57	.221591	.252942	.3072	.363085
.58	.216088	.247159	.301066	.356743
.59	.210742	.241527	.295074	.350529
.6	.205548	.236044	.28922	.34444
.61	.200502	.230706	.283501	.338474
.62	.195599	.225507	.277914	.332629
.63	.190836	.220445	.272456	.326901
.64	.186207	.215517	.267124	.32129
.65	.18171	.210717	.261916	.315793
.66	.17734	.206043	.256827	.310407
.67	.173093	.201492	.251856	.305131
.68	.168966	.19706	.247	.299962
.69	.164956	.192743	.242256	.294898
.7	.161057	.188539	.237621	.289937
.71	.157268	.184444	.233092	.285077
.72	.153585	.180456	.228668	.280316
.73	.150005	.176571	.224346	.275652
.74	.146525	.172787	.220123	.271083
.75	.143141	.169101	.215997	.266606
.76	.139851	.16551	.211963	.262221
.77	.136653	.162011	.208026	.257924
.78	.133542	.158603	.204176	.253715
.79	.130517	.155281	.200414	.249591
.8	.127575	.152045	.196738	.245551
.81	.124713	.148891	.193146	.241593
.82	.12193	.145817	.189634	.237714
.83	.119222	.142821	.186203	.233914
.84	.116588	.139901	.182849	.230191
.85	.114025	.137055	.17957	.226542
.86	.111531	.134281	.176365	.222967
.87	.109104	.131576	.173232	.219464
.88	.106742	.128939	.17017	.216031
.89	.104443	.126368	.167175	.212666
.9	.102205	.12386	.164248	.209369

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\bar{X}$	.5th	1st	2.5th	5th
.91	.100027	.121415	.161385	.206138
.92	.097906	.11903	.158586	.20297
.93	.095842	.116705	.155849	.199866
.94	.093831	.114436	.153172	.196823
.95	.091873	.112223	.150554	.19384
.96	.089966	.110063	.147994	.190916
.97	.088108	.107957	.145489	.18805
.98	.086299	.105901	.143039	.18524
.99	.084536	.103895	.140642	.182485
1.	.082819	.101938	.138297	.179783

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	10th	20th	30th	40th
.5	.488238	.601014	.698173	.793541
.51	.481044	.594362	.692297	.788666
.52	.473965	.587781	.686457	.783794
.53	.467	.581272	.680654	.778927
.54	.460146	.574834	.674888	.774066
.55	.453404	.568468	.669161	.769213
.56	.446771	.562174	.663473	.764369
.57	.440247	.555951	.657824	.759535
.58	.43383	.5498	.652217	.754712
.59	.427519	.54372	.64665	.749902
.6	.421313	.537712	.641126	.745106
.61	.41521	.531775	.635644	.740324
.62	.409209	.525908	.630205	.735559
.63	.403308	.520113	.624809	.73081
.64	.397506	.514387	.619457	.726078
.65	.391803	.508732	.61415	.721366
.66	.386196	.503147	.608887	.716673
.67	.380683	.497631	.603669	.712
.68	.375265	.492183	.598496	.707348
.69	.369939	.486805	.593368	.702719
.7	.364703	.481494	.588287	.698112
.71	.359557	.476251	.583251	.693528
.72	.354499	.471075	.578261	.688968
.73	.349528	.465965	.573317	.684433
.74	.344642	.460922	.568419	.679923
.75	.33984	.455943	.563567	.675438
.76	.33512	.45103	.558762	.670979
.77	.330482	.446181	.554003	.666548
.78	.325924	.441395	.549289	.662143
.79	.321444	.436673	.544622	.657765
.8	.317041	.432013	.540001	.653416
.81	.312715	.427415	.535426	.649094
.82	.308462	.422877	.530897	.644802
.83	.304284	.418401	.526413	.640537
.84	.300177	.413984	.521975	.636303
.85	.296141	.409626	.517582	.632097
.86	.292174	.405327	.513234	.627921
.87	.288276	.401085	.508931	.623775
.88	.284445	.396901	.504672	.619658
.89	.28068	.392773	.500458	.615572
.9	.276979	.388701	.496289	.611516

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\bar{X}$	10th	20th	30th	40th
.91	.273342	.384684	.492163	.607491
.92	.269767	.380721	.48808	.603495
.93	.266254	.376812	.484042	.599531
.94	.2628	.372956	.480046	.595597
.95	.259406	.369152	.476093	.591694
.96	.256069	.3654	.472182	.587821
.97	.25279	.361699	.468313	.583979
.98	.249566	.358048	.464487	.580168
.99	.246397	.354447	.460701	.576387
1.	.243282	.350895	.456957	.572638

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\bar{X}$	60th	70th	80th	90th
.5	1.09814	1.14585	1.33108	1.63854
.51	1.00624	1.14631	1.33519	1.64972
.52	1.00429	1.14669	1.33919	1.66078
.53	1.00228	1.14699	1.34309	1.67174
.54	1.00022	1.1472	1.34688	1.68258
.55	.998103	1.14734	1.35057	1.69331
.56	.99594	1.1474	1.35415	1.70393
.57	.993731	1.14738	1.35763	1.71443
.58	.991475	1.14729	1.361	1.72482
.59	.989174	1.14712	1.36428	1.73509
.6	.986831	1.14688	1.36745	1.74524
.61	.984446	1.14657	1.37052	1.75528
.62	.982021	1.14619	1.3735	1.7652
.63	.979557	1.14574	1.37638	1.775
.64	.977057	1.14523	1.37916	1.78466
.65	.974522	1.14465	1.38184	1.79424
.66	.971953	1.14401	1.38443	1.80368
.67	.969351	1.14331	1.38693	1.813
.68	.966718	1.14254	1.38933	1.8222
.69	.964056	1.14172	1.39165	1.83128
.7	.961365	1.14084	1.39387	1.84024
.71	.958647	1.1399	1.39601	1.84908
.72	.955904	1.13891	1.39805	1.8578
.73	.953136	1.13787	1.40001	1.8664
.74	.950345	1.13677	1.40189	1.87488
.75	.947532	1.13562	1.40368	1.88324
.76	.944699	1.13443	1.40539	1.89148
.77	.941846	1.13318	1.40702	1.8996
.78	.938974	1.13189	1.40857	1.90761
.79	.936086	1.13055	1.41004	1.9155
.8	.933181	1.12917	1.41143	1.92327
.81	.930261	1.12775	1.41274	1.93092
.82	.927328	1.12629	1.41398	1.93846
.83	.924381	1.12478	1.41515	1.94588
.84	.921422	1.12324	1.41625	1.95319
.85	.918452	1.12166	1.41727	1.96039
.86	.915472	1.12004	1.41822	1.96747
.87	.912483	1.11839	1.41911	1.97444
.88	.909485	1.11671	1.41993	1.9813
.89	.90648	1.11499	1.42068	1.98805
.9	.903468	1.11323	1.42136	1.99468

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\overline{X}$	60th	70th	80th	90th
.91	.900451	1.11145	1.42199	2.00121
.92	.897428	1.10964	1.42255	2.00763
.93	.894401	1.1078	1.42305	2.01395
.94	.891371	1.10593	1.42349	2.02015
.95	.888337	1.10404	1.42387	2.02626
.96	.885302	1.10212	1.42419	2.03226
.97	.882265	1.10017	1.42446	2.03815
.98	.879227	1.0982	1.42467	2.04394
.99	.876189	1.09621	1.42482	2.04964
1.	.873151	1.09419	1.42493	2.05523

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	95th	97.5th	99th	99.5th
.5	1.94531	2.25754	2.68412	3.01983
.51	1.9646	2.28599	2.72636	3.07383
.52	1.98381	2.31446	2.76882	3.12824
.53	2.00296	2.34295	2.81148	3.18305
.54	2.02203	2.37145	2.85433	3.23826
.55	2.04103	2.39995	2.89737	3.29385
.56	2.05994	2.42845	2.94059	3.34982
.57	2.07878	2.45694	2.98397	3.40615
.58	2.09752	2.48542	3.02752	3.46284
.59	2.11618	2.51389	3.07122	3.51987
.6	2.13475	2.54233	3.11506	3.57723
.61	2.15322	2.57074	3.15904	3.63492
.62	2.17159	2.59912	3.20315	3.69292
.63	2.18986	2.62747	3.24738	3.75123
.64	2.20803	2.65577	3.29172	3.80983
.65	2.2261	2.68402	3.33616	3.86872
.66	2.24406	2.71222	3.3807	3.92788
.67	2.26191	2.74036	3.42533	3.98731
.68	2.27964	2.76845	3.47005	4.04699
.69	2.29727	2.79647	3.51483	4.10692
.7	2.31478	2.82442	3.55969	4.16708
.71	2.33217	2.85229	3.6046	4.22747
.72	2.34944	2.88009	3.64956	4.28807
.73	2.3666	2.90781	3.69457	4.34889
.74	2.38363	2.93545	3.73962	4.40989
.75	2.40054	2.963	3.78471	4.47109
.76	2.41733	2.99046	3.82981	4.53247
.77	2.43399	3.01782	3.87494	4.59401
.78	2.45052	3.04509	3.92008	4.65572
.79	2.46693	3.07226	3.96522	4.71758
.8	2.48321	3.09932	4.01036	4.77958
.81	2.49936	3.12628	4.0555	4.84172
.82	2.51538	3.15313	4.10063	4.90398
.83	2.53127	3.17987	4.14574	4.96636
.84	2.54703	3.20649	4.19082	5.02885
.85	2.56266	3.233	4.23588	5.09144
.86	2.57815	3.25939	4.2809	5.15412
.87	2.59351	3.28566	4.32588	5.21689
.88	2.60874	3.31181	4.37082	5.27973
.89	2.62384	3.33783	4.41571	5.34265
.9	2.63881	3.36372	4.46054	5.40562

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\bar{X}$	95th	97.5th	99th	99.5th
.91	2.65364	3.38949	4.50532	5.46865
.92	2.66834	3.41513	4.55003	5.53173
.93	2.6829	3.44064	4.59468	5.59485
.94	2.69733	3.46601	4.63925	5.658
.95	2.71163	3.49125	4.68374	5.72118
.96	2.72579	3.51636	4.72816	5.78438
.97	2.73982	3.54132	4.77248	5.84759
.98	2.75372	3.56615	4.81672	5.9108
.99	2.76749	3.59084	4.86087	5.97402
1.	2.78112	3.61539	4.90493	6.03723

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\overline{X}$	.5th	1st	2.5th	5th
1.	.082319	.101938	.138297	.179783
1.01	.081145	.100027	.136003	.177134
1.02	.079515	.098162	.133758	.174537
1.03	.077925	.096342	.131561	.17199
1.04	.076376	.094564	.129412	.169492
1.05	.074866	.092829	.127308	.167043
1.06	.073393	.091135	.125249	.16464
1.07	.071958	.08948	.123233	.162283
1.08	.070558	.087864	.12126	.159972
1.09	.069193	.086286	.119329	.157704
1.1	.067862	.084744	.117438	.15548
1.11	.066563	.083238	.115586	.153297
1.12	.065296	.081767	.113773	.151156
1.13	.06406	.080329	.111998	.149055
1.14	.062855	.078924	.110259	.146993
1.15	.061678	.077551	.108556	.14497
1.16	.06053	.076209	.106889	.142985
1.17	.059409	.074898	.105255	.141036
1.18	.058315	.073616	.103654	.139124
1.19	.057247	.072363	.102086	.137247
1.2	.056204	.071137	.10055	.135404
1.21	.055186	.069939	.099045	.133595
1.22	.054192	.068768	.097569	.131819
1.23	.053221	.067622	.096124	.130076
1.24	.052272	.066501	.094707	.128364
1.25	.051346	.065405	.093318	.126683
1.26	.050441	.064332	.091957	.125032
1.27	.049557	.063283	.090622	.123411
1.28	.048693	.062257	.089314	.121818
1.29	.047849	.061252	.088031	.120255
1.3	.047024	.060269	.086773	.118718
1.31	.046217	.059307	.085539	.11721
1.32	.045429	.058366	.08433	.115727
1.33	.044658	.057444	.083143	.114271
1.34	.043905	.056542	.08198	.11284
1.35	.043168	.055658	.080838	.111434
1.36	.042447	.054793	.079718	.110053
1.37	.041743	.053946	.07862	.108695
1.38	.041053	.053116	.077542	.107361
1.39	.040379	.052304	.076484	.106049
1.4	.03972	.051508	.075446	.10476

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/X̄	.5th	1st	2.5th	5th
1.41	.039074	.050728	.074427	.103493
1.42	.038443	.049965	.073428	.102248
1.43	.037825	.049216	.072446	.101024
1.44	.03722	.048483	.071483	.09982
1.45	.036628	.047764	.070537	.098636
1.46	.036049	.04706	.069609	.097472
1.47	.035482	.04637	.068698	.096328
1.48	.034926	.045694	.067803	.095203
1.49	.034383	.04503	.066924	.094096
1.5	.03385	.04438	.066061	.093007

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	10th	20th	30th	40th
1.	.243282	.350895	.456957	.572638
1.01	.240219	.34739	.453253	.568918
1.02	.237208	.343934	.44959	.56523
1.03	.234248	.340525	.445967	.561572
1.04	.231338	.337161	.442383	.557944
1.05	.228476	.333844	.438839	.554347
1.06	.225663	.330571	.435334	.55078
1.07	.222896	.327343	.431867	.547243
1.08	.220176	.324158	.428438	.543737
1.09	.217501	.321017	.425047	.54026
1.1	.21487	.317918	.421694	.536813
1.11	.212283	.314861	.418377	.533396
1.12	.209739	.311845	.415097	.530008
1.13	.207237	.30887	.411854	.52665
1.14	.204776	.305935	.408646	.52332
1.15	.202355	.303039	.405474	.52002
1.16	.199974	.300182	.402336	.516749
1.17	.197632	.297363	.399234	.513507
1.18	.195327	.294582	.396166	.510293
1.19	.193061	.291839	.393131	.507107
1.2	.19083	.289131	.390131	.50395
1.21	1.88636	.28646	.387163	.500821
1.22	.186478	.283825	.384229	.497719
1.23	.184353	.281224	.381326	.494645
1.24	.1842263	.278658	.378456	.491599
1.25	.180206	.276125	.375618	.48858
1.26	.178182	.273626	.37281	.485587
1.27	.17619	.27116	.370034	.482622
1.28	.174229	.268726	.367288	.479683
1.29	.1723	.266325	.364573	.47677
1.3	.1704	.263954	.361887	.473884
1.31	.168531	.261615	.359231	.471023
1.32	.16669	.259306	.356604	.468188
1.33	.164879	.257027	.354006	.465379
1.34	.163095	.254777	.351436	.462595
1.35	.161339	.252557	.348894	.459836
1.36	.15961	.250365	.34638	.457102
1.37	.157907	.248201	.343893	.454393
1.38	.15623	.246065	.341434	.451708
1.39	.15458	.243957	.339001	.449047
1.4	.152954	.241875	.336595	.44641

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\overline{X}$	10th	20th	30th	40th
1.41	.151353	.23982	.334214	.443797
1.42	.149776	.237791	.331859	.441208
1.43	.148222	.235788	.32953	.438642
1.44	.146692	.23381	.327226	.436098
1.45	.145185	.231857	.324946	.433578
1.46	.143701	.229929	.322691	.431081
1.47	.142238	.228024	.320461	.428606
1.48	.140797	.226144	.318254	.426153
1.49	.139377	.224286	.31607	.423722
1.5	.137979	.222452	.31391	.421313

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	60th	70th	80th	90th
1.	.873151	1.09419	1.42493	2.05523
1.01	.870115	1.09216	1.42498	2.06072
1.02	.86708	1.0901	1.42498	2.06611
1.03	.864046	1.08803	1.42493	2.07141
1.04	.861016	1.08593	1.42483	2.07661
1.05	.857989	1.08382	1.42469	2.08172
1.06	.854965	1.08169	1.4245	2.08673
1.07	.851946	1.07955	1.42426	2.09165
1.08	.84893	1.07739	1.42398	2.09648
1.09	.84592	1.07521	1.42365	2.10122
1.1	.842916	1.07303	1.42328	2.10586
1.11	.839917	1.07082	1.42288	2.11042
1.12	.836924	1.06861	1.42243	2.11489
1.13	.833938	1.06638	1.42194	2.11928
1.14	.830959	1.06414	1.42141	2.12358
1.15	.827987	1.06189	1.42084	2.12779
1.16	.825022	1.05963	1.42024	2.13192
1.17	.822065	1.05737	1.4196	2.13597
1.18	.819117	1.05509	1.41892	2.13994
1.19	.816177	1.0528	1.41821	2.14383
1.2	.813246	1.05051	1.41747	2.14764
1.21	.810324	1.04821	1.4167	2.15137
1.22	.807411	1.0459	1.41589	2.15502
1.23	.804508	1.04358	1.41505	2.1586
1.24	.801614	1.04126	1.41418	2.1621
1.25	.79873	1.03894	1.41328	2.16553
1.26	.795857	1.03661	1.41236	2.16889
1.27	.792994	1.03427	1.4114	2.17217
1.28	.790141	1.03193	1.41042	2.17539
1.29	.787299	1.02959	1.40941	2.17853
1.3	.784468	1.02724	1.40838	2.1816
1.31	.781648	1.0249	1.40731	2.18461
1.32	.778839	1.02254	1.40623	2.18755
1.33	.776042	1.02019	1.40512	2.19042
1.34	.773255	1.01784	1.40399	2.19323
1.35	.770481	1.01548	1.40283	2.19597
1.36	.767718	1.01312	1.40166	2.19865
1.37	.764967	1.01077	1.40046	2.20127
1.38	.762228	1.00841	1.39924	2.20382
1.39	.759501	1.00605	1.398	2.20632
1.4	.756786	1.00369	1.39674	2.20875

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\overline{X}$	60th	70th	80th	90th
1.41	.754083	1.00134	1.39546	2.21113
1.42	.751393	.998978	1.39416	2.21344
1.43	.748715	.996623	1.39285	2.2157
1.44	.746049	.99427	1.39152	2.21791
1.45	.743396	.991917	1.39017	2.22006
1.46	.740755	.989567	1.3888	2.22215
1.47	.738126	.987219	1.38742	2.22419
1.48	.735511	.984874	1.38602	2.22618
1.49	.732907	.982531	1.38461	2.22811
1.5	.730317	.98019	1.38318	2.22999

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\bar{X}$	95th	97.5th	99th	99.5th
1.	2.78112	3.61539	4.90493	6.03723
1.01	2.79462	3.6398	4.94888	6.10043
1.02	2.80799	3.66407	4.99273	6.16361
1.03	2.82123	3.68819	5.03647	6.22677
1.04	2.83434	3.71217	5.0801	6.2899
1.05	2.84731	3.736	5.12363	6.35299
1.06	2.86016	3.75969	5.16703	6.41605
1.07	2.87288	3.78324	5.21032	6.47906
1.08	2.88547	3.80664	5.25348	6.54201
1.09	2.89793	3.82989	5.29653	6.60492
1.1	2.91027	3.85299	5.33944	6.66776
1.11	2.92247	3.87595	5.38223	6.73053
1.12	2.93456	3.89876	5.42489	6.79324
1.13	2.94651	3.92143	5.46741	6.85587
1.14	2.95834	3.94394	5.50979	6.91843
1.15	2.97005	3.96631	5.55204	6.9809
1.16	2.98163	3.98853	5.59415	7.03428
1.17	2.9931	4.0106	5.63612	7.10558
1.18	3.00443	4.03252	5.67794	7.16778
1.19	3.01565	4.0543	5.71962	7.22988
1.2	3.02675	4.07593	5.76115	7.29187
1.21	3.03773	4.09741	5.80253	7.35376
1.22	3.04859	4.11874	5.84376	7.41554
1.23	3.05934	4.13992	5.88484	7.47721
1.24	3.06996	4.16096	5.92577	7.53876
1.25	3.08047	4.18185	5.96654	7.6002
1.26	3.09087	4.20259	6.00716	7.66151
1.27	3.10115	4.22319	6.04762	7.72269
1.28	3.11132	4.24364	6.08792	7.78375
1.29	3.12138	4.26395	6.12806	7.84467
1.3	3.13132	4.28411	6.16805	7.90546
1.31	3.14116	4.30413	6.20787	7.96612
1.32	3.15088	4.324	6.24753	8.02663
1.33	3.1605	4.34373	6.28702	8.08701
1.34	3.17001	4.36331	6.32636	8.14724
1.35	3.17941	4.38276	6.36552	8.20732
1.36	3.1887	4.40206	6.40453	8.26725
1.37	3.19789	4.42122	6.44337	8.32704
1.38	3.20698	4.44023	6.48204	8.38667
1.39	3.21596	4.45911	6.52054	8.44615
1.4	3.22485	4.47785	6.55888	8.50547

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	95th	97.5th	99th	99.5th
1.41	3.23363	4.49645	6.59705	8.56464
1.42	3.24231	4.51491	6.63506	8.62364
1.43	3.25089	4.53323	6.67289	8.68248
1.44	3.25937	4.55142	6.71056	8.74116
1.45	3.26775	4.56947	6.74806	8.79968
1.46	3.27604	4.58738	6.78539	8.85802
1.47	3.28423	4.60516	6.82255	8.9162
1.48	3.29233	4.6228	6.85954	8.97422
1.49	3.30034	4.64032	6.89636	9.03206
1.5	3.30825	4.65769	6.93302	9.08973

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	.5th	1st	2.5th	5th
1.5	.03385	.04438	.066061	.093007
1.51	.033329	.043743	.065213	.091936
1.52	.032818	.043118	.06438	.090883
1.53	.032318	.042505	.063562	.089847
1.54	.031828	.041904	.062759	.088828
1.55	.031347	.041314	.06197	.087825
1.56	.030877	.040736	.061194	.086838
1.57	.030416	.040169	.060432	.085867
1.58	.029964	.039612	.059684	.084911
1.59	.029522	.039066	.058948	.083971
1.6	.029088	.03853	.058225	.083046
1.61	.028662	.038005	.057514	.082135
1.62	.028246	.037489	.056816	.081238
1.63	.027837	.036982	.056129	.080356
1.64	.027436	.036485	.055454	.079487
1.65	.027043	.035998	.05479	.078632
1.66	.026657	.035519	.054138	.07779
1.67	.026279	.035048	.053496	.076961
1.68	.025909	.034587	.052865	.076145
1.69	.025545	.034134	.052245	.075341
1.7	.025188	.033688	.051635	.074549
1.71	.024838	.033251	.051034	.073769
1.72	.024495	.032822	.050444	.073002
1.73	.024158	.0324	.049863	.072245
1.74	.023827	.031986	.049292	.0715
1.75	.023503	.031579	.04873	.070767
1.76	.023184	.031179	.048177	.070044
1.77	.022871	.030787	.047633	.069331
1.78	.022565	.030401	.047098	.06863
1.79	.022263	.030021	.046571	.067938
1.8	.021967	.029649	.046053	.067257
1.81	.021677	.029282	.045542	.066586
1.82	.021392	.028922	.04504	.065924
1.83	.021112	.028568	.044546	.065272
1.84	.020837	.02822	.044059	.064629
1.85	.020566	.027878	.04358	.063996
1.86	.020301	.027542	.043108	.063372
1.87	.02004	.027212	.042644	.062756
1.88	.019784	.026886	.042187	.062149
1.89	.019532	.026567	.041737	.061551
1.9	.019285	.026252	.041293	.060962

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	.5th	1st	2.5th	5th
1.91	.019042	.025943	.040856	.06038
1.92	.018803	.025639	.040426	.059807
1.93	.018569	.02534	.040003	.059242
1.94	.018338	.025045	.039586	.058684
1.95	.018111	.024756	.039175	.058134
1.96	.017889	.024471	.03877	.057592
1.97	.017669	.024191	.038371	.057057
1.98	.017454	.023915	.037978	.05653
1.99	.017242	.023643	.03759	.056009
2.	.017034	.023376	.037209	.055496

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\overline{X}$	10th	20th	30th	40th
1.5	.137979	.222452	.31391	.421313
1.51	.1366	.220641	.311773	.418925
1.52	.135242	.218852	.309658	.416559
1.53	.133903	.217085	.307566	.414214
1.54	.132584	.21534	.305496	.41189
1.55	.131284	.213616	.303448	.409586
1.56	.130003	.211913	.301421	.407304
1.57	.12874	.210231	.299416	.405041
1.58	.127495	.20857	.297431	.402799
1.59	.126267	.206928	.295468	.400576
1.6	.125058	.205307	.293524	.398373
1.61	.123865	.203704	.291601	.39619
1.62	.122689	.202121	.289698	.394026
1.63	.121529	.200557	.287815	.391881
1.64	.120396	.199012	.285951	.389755
1.65	.119259	.197485	.284106	.387648
1.66	.118147	.195976	.28228	.385559
1.67	.11705	.194485	.280473	.383489
1.68	.115969	.193011	.278684	.381437
1.69	.114903	.191555	.276913	.379402
1.7	.113851	.190116	.275161	.377386
1.71	.112813	.188693	.273426	.375387
1.72	.11179	.187287	.271709	.373405
1.73	.11078	.185898	.270009	.371441
1.74	.109784	.184524	.268327	.369493
1.75	.108802	.183167	.266661	.367563
1.76	.107832	.181824	.265012	.365649
1.77	.106876	.180498	.263379	.363752
1.78	.105932	.179186	.261762	.361871
1.79	.105001	.177889	.260162	.360006
1.8	.104081	.176607	.258577	.358157
1.81	.103174	.17534	.257009	.356324
1.82	.102279	.174086	.255455	.354506
1.83	.101396	.172847	.253917	.352704
1.84	.100524	.171622	.252394	.350918
1.85	.099663	.17041	.250886	.349146
1.86	.098814	.169212	.249392	.34739
1.87	.097975	.168027	.247913	.345648
1.88	.097147	.166855	.246448	.343921
1.89	.09633	.165696	.244998	.342208
1.9	.095523	.16455	.243561	.34051

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\bar{X}$	10th	20th	30th	40th
1.91	.094726	.163416	.242138	.338826
1.92	.093939	.162295	.240729	.337156
1.93	.093163	.161186	.239334	.3355
1.94	.092395	.160089	.237951	.333858
1.95	.091638	.159004	.236582	.33223
1.96	.09089	.15793	.235226	.330614
1.97	.090151	.156868	.233882	.329013
1.98	.089421	.155817	.232551	.327424
1.99	.088701	.154778	.231233	.325849
2.	.087989	.153749	.229927	.324286

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\overline{X}$	60th	70th	80th	90th
1.5	.730317	.98019	1.38318	2.22999
1.51	.727739	.977853	1.38174	2.23182
1.52	.725174	.975519	1.38028	2.23361
1.53	.722622	.973188	1.37881	2.23534
1.54	.720082	.970861	1.37733	2.23702
1.55	.717556	.968538	1.37584	2.23866
1.56	.715042	.966219	1.37433	2.24025
1.57	.71254	.963904	1.37281	2.24179
1.58	.710052	.961593	1.37128	2.24329
1.59	.707576	.959287	1.36974	2.24474
1.6	.705113	.956985	1.36819	2.24615
1.61	.702663	.954688	1.36663	2.24751
1.62	.700226	.952396	1.36506	2.24883
1.63	.697801	.950108	1.36348	2.25011
1.64	.695389	.947826	1.36189	2.25135
1.65	.69299	.94555	1.36029	2.25255
1.66	.690603	.943278	1.35868	2.2537
1.67	.688229	.941012	1.35706	2.25482
1.68	.685868	.938752	1.35544	2.2559
1.69	.683519	.936497	1.35381	2.25694
1.7	.681183	.934249	1.35217	2.25794
1.71	.67886	.932006	1.35052	2.2589
1.72	.676549	.929769	1.34887	2.25983
1.73	.67425	.927538	1.34721	2.26072
1.74	.671964	.925314	1.34555	2.26158
1.75	.66969	.923095	1.34388	2.2624
1.76	.667429	.920883	1.3422	2.26318
1.77	.66518	.918678	1.34052	2.26394
1.78	.662943	.916478	1.33883	2.26465
1.79	.660719	.914286	1.33714	2.26534
1.8	.658506	.9121	1.33544	2.26599
1.81	.656306	.90992	1.33374	2.26661
1.82	.654118	.907748	1.33203	2.26721
1.83	.651942	.905582	1.33032	2.26776
1.84	.649778	.903423	1.32861	2.26829
1.85	.647626	.901271	1.32689	2.26879
1.86	.645485	.899126	1.32517	2.26926
1.87	.643357	.896987	1.32345	2.2697
1.88	.64124	.894856	1.32172	2.27012
1.89	.639135	.892732	1.31999	2.8705
1.9	.637042	.890615	1.31826	2.27086

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\bar{X}$	60th	70th	80th	90th
1.91	.63496	.888505	1.31652	2.27119
1.92	.63289	.886402	1.31478	2.27149
1.93	.630832	.884306	1.31304	2.27177
1.94	.628784	.882218	1.3113	2.27202
1.95	.626749	.880137	1.30956	2.27224
1.96	.624724	.878063	1.30781	2.27244
1.97	.622711	.875996	1.30606	2.27262
1.98	.620709	.873936	1.30432	2.27277
1.99	.618718	.871884	1.30257	2.2729
2.	.616738	.869889	1.30081	2.273

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	95th	97.5th	99th	99.5th
1.5	3.30825	4.65769	6.93302	9.08973
1.51	3.31607	4.67494	6.9695	9.14723
1.52	3.32379	4.69205	7.00581	9.20455
1.53	3.33143	4.70904	7.04196	9.2617
1.54	3.33898	4.72589	7.07793	9.31867
1.55	3.34644	4.74262	7.11374	9.37547
1.56	3.35381	4.75922	7.14938	9.43209
1.57	3.36109	4.77569	7.18484	9.48853
1.58	3.36829	4.79203	7.22014	9.54479
1.59	3.37541	4.80825	7.25527	9.60087
1.6	3.38244	4.82434	7.29024	9.65677
1.61	3.38939	4.84031	7.32503	9.71249
1.62	3.39625	4.85616	7.35966	9.76802
1.63	3.40303	4.87188	7.39412	9.82338
1.64	3.40973	4.88748	7.42841	9.87855
1.65	3.41636	4.90296	7.46253	9.93353
1.66	3.4229	4.91832	7.49649	9.98834
1.67	3.42937	4.93356	7.53028	10.043
1.68	3.43575	4.94869	7.56391	10.0974
1.69	3.44206	4.96369	7.59737	10.1516
1.7	3.4483	4.97858	7.63067	10.2057
1.71	3.45446	4.99335	7.6638	10.2596
1.72	3.46055	5.00801	7.69677	10.3133
1.73	3.46656	5.02255	7.72957	10.3668
1.74	3.4725	5.03698	7.76221	10.4201
1.75	3.47837	5.0513	7.79469	10.4732
1.76	3.48417	5.06551	7.82701	10.5262
1.77	3.48989	5.0796	7.85916	10.5789
1.78	3.49555	5.09359	7.89115	10.6315
1.79	3.50114	5.10746	7.92299	10.6839
1.8	3.50666	5.12123	7.95466	10.7361
1.81	3.51211	5.13489	7.98618	10.7881
1.82	3.5175	5.14844	8.01753	10.8399
1.83	3.52282	5.16188	8.04873	10.8915
1.84	3.52807	5.17522	8.07977	10.943
1.85	3.53326	5.18846	8.11065	10.9942
1.86	3.53839	5.20159	8.14138	11.0453
1.87	3.54345	5.21462	8.17195	11.0962
1.88	3.54845	5.22755	8.20236	11.1469
1.89	3.55339	5.24037	8.23262	11.1974
1.9	3.55827	5.2531	8.26273	11.2477

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	95th	97.5th	99th	99.5th
1.91	3.56309	5.26573	8.29268	11.2979
1.92	3.56785	5.27825	8.32249	11.3478
1.93	3.57254	5.29068	8.35214	11.3976
1.94	3.57718	5.30301	8.38163	11.4472
1.95	3.58177	5.31525	8.41098	11.4966
1.96	3.58629	5.32738	8.44018	11.5458
1.97	3.59076	5.33943	8.46923	11.5948
1.98	3.59517	5.35138	8.49813	11.6437
1.99	3.59953	5.36323	8.52688	11.6923
2.	3.60383	5.37499	8.55549	11.7408

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\overline{X}$	.5th	1st	2.5th	5th
2.	.017034	.023376	.037209	.055496
2.01	.016829	.023113	.036833	.05499
2.02	.016628	.022855	.036462	.05449
2.03	.01643	.0226	.036097	.053997
2.04	.016235	.022349	.035737	.053511
2.05	.016044	.022103	.035382	.053031
2.06	.015855	.02186	.035033	.052558
2.07	.01567	.02162	.034688	.05209
2.08	.015487	.021385	.034348	.051629
2.09	.015308	.021153	.034013	.051174
2.1	.015131	.020924	.033683	.050725
2.11	.014957	.0207	.033357	.050282
2.12	.014786	.020478	.033036	.049844
2.13	.014618	.02026	.032719	.049413
2.14	.014452	.020045	.032407	.048986
2.15	.014289	.019833	.032099	.048565
2.16	.014129	.019625	.031795	.04815
2.17	.013971	.019419	.031496	.04774
2.18	.013815	.019217	.0312	.047335
2.19	.013662	.019017	.030909	.046935
2.2	.013511	.018821	.030621	.04654
2.21	.013363	.018627	.030338	.04615
2.22	.013217	.018436	.030058	.045765
2.23	.013073	.018248	.029782	.045384
2.24	.012931	.018063	.02951	.045009
2.25	.012791	.01788	.029241	.044638
2.26	.012654	.0177	.028976	.044272
2.27	.012518	.017523	.028714	.04391
2.28	.012385	.017348	.028456	.043552
2.29	.012254	.017175	.028201	.043199
2.3	.012124	.017005	.027949	.04285
2.31	.011996	.016838	.027701	.042506
2.32	.011871	.016672	.027456	.042165
2.33	.011747	.016509	.027214	.041829
2.34	.011625	.016348	.026975	.041496
2.35	.011505	.01619	.026739	.041168
2.36	.011386	.016034	.026507	.040843
2.37	.011269	.015879	.026277	.040523
2.38	.011154	.015727	.02605	.040206
2.39	.01104	.015577	.025826	.039892
2.4	.010929	.015429	.025605	.039583

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	.5th	1st	2.5th	5th
2.41	.010818	.015283	.025386	.039277
2.42	.010709	.015139	.025171	.038974
2.43	.010602	.014997	.024958	.038676
2.44	.010497	.014857	.024747	.03838
2.45	.010392	.014719	.02454	.038088
2.46	.01029	.014582	.024334	.037799
2.47	.010188	.014448	.024132	.037514
2.48	.010088	.014315	.023931	.037232
2.49	.00999	.014184	.023734	.036953
2.5	.009892	.014054	.023538	.036677

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	10th	20th	30th	40th
2.	.087989	.153749	.229927	.324286
2.01	.087286	.152732	.228633	.322736
2.02	.086591	.151725	.227351	.321199
2.03	.085905	.150729	.226081	.319674
2.04	.085227	.149743	.224823	.318162
2.05	.084557	.148767	.223577	.316662
2.06	.083896	.147802	.222342	.315174
2.07	.083242	.146847	.221118	.313698
2.08	.082596	.145901	.219906	.312234
2.09	.081957	.144966	.218704	.310782
2.1	.081327	.14404	.217514	.309341
2.11	.080703	.143123	.216334	.307912
2.12	.080087	.142216	.215165	.306494
2.13	.079478	.141318	.214006	.305088
2.14	.078877	.140429	.212858	.303692
2.15	.078282	.139549	.211721	.302308
2.16	.077694	.138678	.210593	.300934
2.17	.077113	.137816	.209475	.299572
2.18	.076539	.136962	.208368	.29822
2.19	.075971	.136117	.20727	.296879
2.2	.075409	.135281	.206182	.295548
2.21	.074854	.134452	.205103	.294227
2.22	.074306	.133632	.204034	.292917
2.23	.073763	.13282	.202974	.291617
2.24	.073227	.132016	.201924	.290327
2.25	.072697	.13122	.200883	.289046
2.26	.072172	.130431	.19985	.287776
2.27	.071654	.12965	.198827	.286516
2.28	.071141	.128877	.197812	.285265
2.29	.070634	.128112	.196807	.284023
2.3	.070132	.127353	.19581	.282791
2.31	.069636	.126602	.194821	.281569
2.32	.069145	.125858	.193841	.280355
2.33	.06866	.125121	.192869	.279151
2.34	.06818	.124392	.191905	.277956
2.35	.067705	.123669	.19095	.27677
2.36	.067236	.122953	.190002	.275593
2.37	.066771	.122244	.189063	.274424
2.38	.066311	.121541	.188131	.273265
2.39	.065857	.120845	.187207	.272114
2.4	.065407	.120155	.186291	.270971

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\overline{X}$	10th	20th	30th	40th
2.41	.064962	.119472	.185383	.269837
2.42	.064521	.118796	.184482	.268711
2.43	.064085	.118125	.183588	.267594
2.44	.063654	.117461	.182702	.266484
2.45	.063228	.116802	.181823	.265383
2.46	.062885	.11615	.180952	.26429
2.47	.062388	.115504	.180087	.263205
2.48	.061974	.114864	.179229	.262128
2.49	.061565	.114229	.178379	.261058
2.5	.06116	.1136	.177535	.259996

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\overline{X}$	60th	70th	80th	90th
2.	.616738	.869839	1.30081	2.273
2.01	.614769	.867802	1.29906	2.27308
2.02	.612811	.865772	1.29731	2.27314
2.03	.610865	.863749	1.29556	2.27318
2.04	.608928	.861734	1.2938	2.27319
2.05	.607003	.859726	1.29205	2.27318
2.06	.605088	.857725	1.29029	2.27316
2.07	.603184	.855732	1.28854	2.27311
2.08	.601291	.853746	1.28678	2.27303
2.09	.599408	.851768	1.28503	2.27294
2.1	.597536	.849796	1.28327	2.27283
2.11	.595674	.847833	1.28152	2.2727
2.12	.593822	.845877	1.27977	2.27255
2.13	.591981	.843928	1.27801	2.27238
2.14	.59015	.841986	1.27626	2.2722
2.15	.588329	.840052	1.27451	2.27199
2.16	.586518	.838126	1.27275	2.27177
2.17	.584717	.836206	1.271	2.27153
2.18	.582926	.834294	1.26925	2.27127
2.19	.581145	.83239	1.2675	2.27099
2.2	.579373	.830492	1.26576	2.2707
2.21	.577612	.828603	1.26401	2.27039
2.22	.57586	.82672	1.26226	2.27006
2.23	.574118	.824845	1.26052	2.26972
2.24	.572386	.822977	1.25878	2.26936
2.25	.570663	.821116	1.25704	2.26898
2.26	.568949	.819263	1.2553	2.26859
2.27	.567245	.817417	1.25356	2.26819
2.28	.56555	.815578	1.25182	2.26777
2.29	.563865	.813746	1.25009	2.26734
2.3	.562189	.811922	1.24835	2.26689
2.31	.560522	.810105	1.24662	2.26642
2.32	.558864	.808295	1.24489	2.26595
2.33	.557215	.8064[illegible]2	1.24317	2.26546
2.34	.555575	.804696	1.24144	2.26495
2.35	.553944	.802907	1.23972	2.26444
2.36	.552322	.801126	1.238	2.26391
2.37	.550708	.799352	1.23628	2.26336
2.38	.549104	.797584	1.23457	2.26281
2.39	.547508	.795824	1.23285	2.26224
2.4	.54592	.794071	1.23114	2.26166

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	60th	70th	80th	90th
2.41	.544342	.792324	1.22943	2.26107
2.42	.542772	.790585	1.22773	2.26047
2.43	.54121	.788853	1.22602	2.26985
2.44	.539657	.787127	1.22432	2.25923
2.45	.538112	.785409	1.22262	2.25859
2.46	.536575	.783697	1.22093	2.25794
2.47	.535046	.781993	1.21924	2.25728
2.48	.533526	.780295	1.21754	2.25661
2.49	.532014	.778604	1.21586	2.25593
2.5	.53051	.776919	1.21417	2.25524

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

S/$\bar{X}$	95th	97.5th	99th	99.5th
2.	3.60383	5.37499	8.55549	11.7408
2.01	3.60808	5.38666	8.58395	11.7891
2.02	3.61227	5.39824	8.61226	11.8372
2.03	3.61641	5.40973	8.64043	11.8852
2.04	3.6203	5.42113	8.66845	11.9329
2.05	3.62454	5.43244	8.69633	11.9805
2.06	3.62853	5.44366	8.72407	12.0279
2.07	3.63246	5.45479	8.75167	12.0751
2.08	3.63634	5.46583	8.77912	12.1221
2.09	3.64018	5.47679	8.80643	12.169
2.1	3.64397	5.48767	8.83361	12.2157
2.11	3.6477	5.49846	8.86064	12.2622
2.12	3.65139	5.50916	8.88754	12.3085
2.13	3.65503	5.51978	8.91429	12.3546
2.14	3.65863	5.53032	8.94091	12.4006
2.15	3.66218	5.54077	8.9674	12.4464
2.16	3.66568	5.55114	8.99374	12.492
2.17	3.66914	5.56144	9.01996	12.5374
2.18	3.67255	5.57165	9.04604	12.5827
2.19	3.67591	5.58178	9.07198	12.6278
2.2	3.67924	5.59184	9.09779	12.6727
2.21	3.68252	5.60181	9.12347	12.7174
2.22	3.68575	5.61171	9.14902	12.762
2.23	3.68895	5.62153	9.17444	12.8064
2.24	3.6921	5.63127	9.19972	12.8506
2.25	3.69521	5.64094	9.22488	12.8947
2.26	3.69828	5.65053	9.24991	12.9386
2.27	3.70131	5.66005	9.27481	12.9823
2.28	3.70429	5.6695	9.29959	13.0258
2.29	3.70724	5.67887	9.32423	13.0692
2.3	3.71015	5.68817	9.34875	13.1124
2.31	3.71302	5.69739	9.37315	13.1554
2.32	3.71585	5.70655	9.39742	13.1983
2.33	3.71864	5.71563	9.42157	13.241
2.34	3.7214	5.72464	9.4456	13.2836
2.35	3.72412	5.73359	9.4695	13.326
2.36	3.7268	5.74246	9.49328	13.3682
2.37	3.72944	5.75127	9.51694	13.4102
2.38	3.73205	5.76	9.54048	13.4521
2.39	3.73462	5.76867	9.5639	13.4938
2.4	3.73716	5.77728	9.5872	13.5354

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

$S/\overline{X}$	95th	97.5th	99th	99.5th
2.41	3.73966	5.78581	9.61038	13.5768
2.42	3.74213	5.79428	9.63345	13.6181
2.43	3.74456	5.80269	9.6564	13.6592
2.44	3.74696	5.81103	9.67923	13.7001
2.45	3.74932	5.8193	9.70195	13.7408
2.46	3.75165	5.82752	9.72455	13.7815
2.47	3.75395	5.83567	9.74704	13.8219
2.48	3.75622	5.84375	9.76941	13.8622
2.49	3.75845	5.85178	9.79167	13.9023
2.5	3.76066	5.85974	9.81382	13.9423

*TABLE V. PERCENTAGE POINTS, b_γ, SUCH THAT $P[\hat{c}/c < b_\gamma] = \gamma$

N \ γ	0.02	0.05	0.10	0.25	0.40	0.50	0.60
5	0.604	0.683	0.766	0.951	1.116	1.238	1.378
6	0.623	0.697	0.778	0.937	1.080	1.188	1.304
7	0.639	0.709	0.785	0.930	1.059	1.155	1.256
8	0.653	0.720	0.792	0.926	1.045	1.131	1.223
9	0.665	0.729	0.797	0.925	1.035	1.114	1.198
10	0.676	0.738	0.802	0.924	1.028	1.101	1.179
11	0.686	0.745	0.807	0.924	1.022	1.090	1.163
12	0.695	0.752	0.811	0.924	1.017	1.082	1.151
13	0.703	0.759	0.815	0.924	1.014	1.075	1.140
14	0.710	0.764	0.819	0.925	1.011	1.069	1.132
15	0.716	0.770	0.823	0.925	1.008	1.064	1.124
16	0.723	0.775	0.826	0.926	1.006	1.059	1.117
17	0.728	0.779	0.829	0.927	1.004	1.056	1.111
18	0.734	0.784	0.832	0.927	1.003	1.052	1.106
19	0.739	0.788	0.835	0.928	1.001	1.049	1.101
20	0.743	0.791	0.838	0.929	1.000	1.047	1.097
22	0.752	0.798	0.843	0.930	0.998	1.042	1.090
24	0.759	0.805	0.848	0.932	0.997	1.038	1.084
26	0.766	0.810	0.852	0.933	0.995	1.035	1.079
28	0.772	0.815	0.856	0.934	0.994	1.033	1.074
30	0.778	0.820	0.860	0.935	0.993	1.030	1.070
32	0.783	0.824	0.863	0.937	0.993	1.028	1.067
34	0.788	0.828	0.866	0.938	0.992	1.027	1.064
36	0.793	0.832	0.869	0.939	0.992	1.025	1.061
38	0.797	0.835	0.872	0.940	0.991	1.024	1.059
40	0.801	0.839	0.875	0.940	0.991	1.023	1.056
42	0.804	0.842	0.877	0.941	0.990	1.022	1.054
44	0.808	0.845	0.880	0.942	0.990	1.021	1.052
46	0.811	0.847	0.882	0.943	0.990	1.020	1.051
48	0.814	0.850	0.884	0.944	0.990	1.019	1.049
50	0.817	0.852	0.886	0.944	0.989	1.018	1.048
52	0.820	0.854	0.888	0.945	0.989	1.017	1.046
54	0.822	0.857	0.890	0.946	0.989	1.017	1.045
56	0.825	0.859	0.891	0.946	0.989	1.016	1.044
58	0.827	0.861	0.893	0.947	0.989	1.015	1.043
60	0.830	0.863	0.894	0.948	0.989	1.015	1.041
62	0.832	0.864	0.896	0.948	0.989	1.014	1.040
64	0.834	0.866	0.897	0.949	0.989	1.014	1.040

*Reproduced from "Inferences on the Parameters of the Weibull Distribution," by Darrel R. Thoman, Lee J. Bain, and Charles E. Antle, Technometrics, Vol. 11 No. 3, (1969), pp. 445-460.

TABLE V. PERCENTAGE POINTS, b_γ, SUCH THAT

$P[\hat{c}/c < b_\gamma] = \gamma$ (Continued)

N \ γ	0.70	0.75	0.80	0.85	0.90	0.95	0.98
66	0.836	0.868	0.899	0.949	0.988	1.014	1.039
68	0.838	0.869	0.900	0.950	0.988	1.013	1.038
70	0.840	0.871	0.901	0.950	0.988	1.013	1.037
72	0.841	0.872	0.903	0.951	0.988	1.012	1.036
74	0.843	0.874	0.904	0.951	0.988	1.012	1.036
76	0.845	0.875	0.905	0.952	0.988	1.012	1.035
78	0.846	0.876	0.906	0.952	0.988	1.011	1.034
80	0.848	0.878	0.907	0.952	0.988	1.011	1.034
85	0.852	0.881	0.910	0.953	0.988	1.011	1.032
90	0.855	0.883	0.912	0.954	0.988	1.010	1.031
95	0.858	0.886	0.914	0.955	0.988	1.009	1.030
100	0.861	0.888	0.916	0.956	0.988	1.009	1.029
110	0.866	0.893	0.920	0.958	0.988	1.008	1.027
120	0.871	0.897	0.923	0.959	0.988	1.007	1.025

TABLE V. PERCENTAGE POINTS, b_γ, SUCH THAT

$P\{\hat{c}/c < b_\gamma\} = \gamma$ (Continued)

N \ γ	0.70	0.75	0.80	0.85	0.90	0.95	0.98
5	1.557	1.671	1.812	2.001	2.277	2.779	3.518
6	1.453	1.543	1.662	1.812	2.030	2.436	3.067
7	1.386	1.461	1.561	1.688	1.861	2.183	2.640
8	1.338	1.404	1.491	1.602	1.747	2.015	2.377
9	1.303	1.361	1.439	1.538	1.665	1.896	2.199
10	1.275	1.328	1.399	1.489	1.602	1.807	2.070
11	1.253	1.302	1.367	1.450	1.553	1.738	1.972
12	1.234	1.281	1.341	1.418	1.513	1.682	1.894
13	1.219	1.263	1.319	1.391	1.480	1.636	1.830
14	1.206	1.248	1.300	1.369	1.452	1.597	1.777
15	1.195	1.234	1.284	1.349	1.427	1.564	1.732
16	1.185	1.223	1.270	1.332	1.406	1.535	1.693
17	1.176	1.213	1.258	1.317	1.388	1.510	1.660
18	1.168	1.204	1.247	1.303	1.371	1.487	1.630
19	1.162	1.196	1.237	1.291	1.356	1.467	1.603
20	1.155	1.188	1.228	1.281	1.343	1.449	1.579
22	1.144	1.176	1.213	1.262	1.320	1.418	1.538
24	1.135	1.165	1.200	1.246	1.301	1.392	1.504
26	1.128	1.156	1.189	1.232	1.284	1.370	1.475
28	1.121	1.148	1.180	1.220	1.269	1.351	1.450
30	1.115	1.141	1.171	1.210	1.257	1.334	1.429
32	1.110	1.135	1.164	1.201	1.246	1.319	1.409
34	1.105	1.129	1.157	1.193	1.236	1.306	1.392
36	1.101	1.125	1.151	1.186	1.227	1.294	1.377
38	1.097	1.120	1.146	1.179	1.219	1.283	1.363
40	1.094	1.116	1.141	1.173	1.211	1.273	1.351
42	1.091	1.112	1.137	1.167	1.204	1.265	1.339
44	1.088	1.109	1.132	1.162	1.198	1.256	1.329
46	1.085	1.106	1.129	1.158	1.192	1.249	1.319
48	1.083	1.103	1.125	1.153	1.187	1.242	1.310
50	1.081	1.100	1.122	1.149	1.182	1.235	1.301
52	1.078	1.098	1.119	1.145	1.177	1.229	1.294
54	1.076	1.095	1.116	1.142	1.173	1.224	1.286
56	1.075	1.093	1.113	1.139	1.169	1.218	1.280
58	1.073	1.091	1.111	1.135	1.165	1.213	1.273
60	1.071	1.089	1.108	1.133	1.162	1.208	1.267
62	1.070	1.087	1.106	1.130	1.158	1.204	1.262
64	1.068	1.086	1.104	1.127	1.155	1.200	1.256
66	1.067	1.084	1.102	1.125	1.152	1.196	1.251
68	1.066	1.083	1.100	1.122	1.149	1.192	1.246
70	1.064	1.081	1.098	1.120	1.146	1.188	1.242
72	1.063	1.080	1.097	1.118	1.144	1.185	1.237

TABLE V. PERCENTAGE POINTS, b_γ, SUCH THAT

$P[\hat{c}/c < b_\gamma] = \gamma$ (Continued)

N \ γ	0.70	0.75	0.80	0.85	0.90	0.95	0.98
74	1.062	1.078	1.095	1.116	1.141	1.182	1.233
76	1.061	1.077	1.093	1.114	1.139	1.179	1.229
78	1.060	1.076	1.092	1.112	1.136	1.176	1.225
80	1.059	1.075	1.090	1.110	1.134	1.173	1.222
85	1.057	1.072	1.087	1.106	1.129	1.166	1.213
90	1.055	1.069	1.084	1.102	1.124	1.160	1.206
95	1.053	1.067	1.081	1.099	1.120	1.155	1.199
100	1.051	1.065	1.079	1.096	1.116	1.150	1.192
110	1.048	1.061	1.074	1.090	1.110	1.141	1.181
120	1.046	1.058	1.070	1.086	1.104	1.133	1.171

*TABLE VI. PERCENTAGE POINTS, ℓ_γ, SUCH THAT

$$P\,[\hat{c}\,\ln(\hat{b}/b) < \ell_\gamma] = \gamma$$

N \ γ	0.02	0.05	0.10	0.25	0.40	0.50	0.60
5	-1.631	-1.247	-0.888	-0.444	-0.241	-0.056	0.085
6	-1.396	-1.007	-0.740	-0.385	-0.194	-0.045	0.079
7	-1.196	-0.874	-0.652	-0.344	-0.168	-0.038	0.074
8	-1.056	-0.784	-0.591	-0.313	-0.150	-0.032	0.070
9	-0.954	-0.717	-0.544	-0.289	-0.137	-0.029	0.067
10	-0.876	-0.665	-0.507	-0.269	-0.126	-0.026	0.065
11	-0.813	-0.622	-0.477	-0.253	-0.118	-0.023	0.062
12	-0.762	-0.587	-0.451	-0.239	-0.111	-0.021	0.061
13	-0.719	-0.557	-0.429	-0.228	-0.106	-0.019	0.059
14	-0.683	-0.532	-0.410	-0.217	-0.100	-0.018	0.057
15	-0.651	-0.509	-0.393	-0.208	-0.096	-0.016	0.056
16	-0.624	-0.489	-0.379	-0.200	-0.092	-0.015	0.054
17	-0.599	-0.471	-0.365	-0.193	-0.089	-0.014	0.053
18	-0.578	-0.455	-0.353	-0.187	-0.085	-0.013	0.052
19	-0.558	-0.441	-0.342	-0.181	-0.083	-0.013	0.051
20	-0.540	-0.428	-0.332	-0.175	-0.080	-0.012	0.050
22	-0.509	-0.404	-0.314	-0.166	-0.075	-0.011	0.048
24	-0.483	-0.384	-0.299	-0.158	-0.071	-0.009	0.047
26	-0.460	-0.367	-0.286	-0.150	-0.068	-0.009	0.046
28	-0.441	-0.352	-0.274	-0.144	-0.065	-0.008	0.044
30	-0.423	-0.338	-0.264	-0.139	-0.062	-0.007	0.043
32	-0.408	-0.326	-0.254	-0.134	-0.059	-0.006	0.042
34	-0.394	-0.315	-0.246	-0.129	-0.057	-0.006	0.041
36	-0.382	-0.305	-0.238	-0.125	-0.055	-0.005	0.040
38	-0.370	-0.296	-0.231	-0.121	-0.053	-0.005	0.040
40	-0.360	-0.288	-0.224	-0.118	-0.052	-0.004	0.039
42	-0.350	-0.280	-0.218	-0.115	-0.050	-0.004	0.038
44	-0.341	-0.273	-0.213	-0.112	-0.048	-0.004	0.037
46	-0.333	-0.266	-0.208	-0.109	-0.047	-0.003	0.037
48	-0.325	-0.260	-0.203	-0.106	-0.046	-0.003	0.036
50	-0.318	-0.254	-0.198	-0.104	-0.045	-0.003	0.036
52	-0.312	-0.249	-0.194	-0.102	-0.043	-0.003	0.035
54	-0.305	-0.244	-0.190	-0.100	-0.042	-0.002	0.035
56	-0.299	-0.239	-0.186	-0.098	-0.041	-0.002	0.034
58	-0.294	-0.234	-0.183	-0.096	-0.040	-0.002	0.034
60	-0.289	-0.230	-0.179	-0.094	-0.039	-0.002	0.033
62	-0.284	-0.226	-0.176	-0.092	-0.039	-0.002	0.033
64	-0.279	-0.222	-0.173	-0.091	-0.038	-0.001	0.032

*Reproduced from "Inferences on the Parameters of the Weibull Distribution," by Darrel R. Thoman, Lee J. Bain, and Charles E. Antle, Technometrics, Vol. 11, No. 3, (1969), pp. 445-460.

TABLE VI. PERCENTAGE POINTS, ℓ_γ, SUCH THAT

$P\,[\hat{c}\,\ln(\hat{b}/b) < \ell_\gamma] = \gamma$ (Continued)

N \ γ	0.02	0.05	0.10	0.25	0.40	0.50	0.60
66	-0.274	-0.218	-0.170	-0.089	-0.037	-0.001	0.032
68	-0.270	-0.215	-0.167	-0.088	-0.036	-0.001	0.032
70	-0.266	-0.211	-0.165	-0.086	-0.035	-0.001	0.031
72	-0.262	-0.208	-0.162	-0.085	-0.035	-0.001	0.031
74	-0.259	-0.205	-0.160	-0.084	-0.034	-0.001	0.031
76	-0.255	-0.202	-0.158	-0.083	-0.033	-0.001	0.030
78	-0.252	-0.199	-0.155	-0.081	-0.033	-0.001	0.030
80	-0.248	-0.197	-0.153	-0.080	-0.032	-0.000	0.030
85	-0.241	-0.190	-0.148	-0.078	-0.031	-0.000	0.029
90	-0.234	-0.184	-0.144	-0.075	-0.030	0.000	0.028
95	-0.227	-0.179	-0.139	-0.073	-0.028	0.000	0.028
100	-0.221	-0.174	-0.136	-0.071	-0.027	0.000	0.027
110	-0.211	-0.165	-0.129	-0.067	-0.025	0.001	0.026
120	-0.202	-0.158	-0.123	-0.064	-0.024	0.001	0.025

TABLE VI. PERCENTAGE POINTS, ℓ_γ, SUCH THAT $P\ [\hat{c}\ \ln(\hat{b}/b) < \ell_\gamma] = \gamma$ (Continued)

N \ γ	0.70	0.75	0.80	0.85	0.90	0.95	0.98
5	0.254	0.349	0.452	0.587	0.772	0.107	1.582
6	0.221	0.302	0.404	0.516	0.666	0.939	1.291
7	0.200	0.272	0.362	0.465	0.598	0.829	1.120
8	0.185	0.251	0.331	0.427	0.547	0.751	1.003
9	0.174	0.235	0.307	0.397	0.507	0.691	0.917
10	0.165	0.222	0.288	0.372	0.475	0.644	0.851
11	0.157	0.211	0.273	0.351	0.448	0.605	0.797
12	0.150	0.202	0.260	0.334	0.425	0.572	0.752
13	0.145	0.194	0.249	0.319	0.406	0.544	0.714
14	0.140	0.187	0.239	0.306	0.389	0.520	0.681
15	0.135	0.180	0.230	0.294	0.374	0.499	0.653
16	0.131	0.175	0.223	0.284	0.360	0.480	0.627
17	0.128	0.170	0.216	0.274	0.348	0.463	0.605
18	0.124	0.165	0.209	0.266	0.338	0.447	0.584
19	0.121	0.161	0.204	0.258	0.328	0.433	0.566
20	0.118	0.157	0.199	0.251	0.318	0.421	0.549
22	0.113	0.150	0.189	0.239	0.302	0.398	0.519
24	0.109	0.144	0.181	0.228	0.288	0.379	0.494
26	0.105	0.138	0.174	0.219	0.276	0.362	0.472
28	0.102	0.134	0.168	0.210	0.265	0.347	0.453
30	0.098	0.129	0.163	0.203	0.256	0.334	0.435
32	0.095	0.125	0.158	0.197	0.247	0.323	0.420
34	0.093	0.122	0.153	0.191	0.239	0.312	0.406
36	0.090	0.118	0.149	0.185	0.232	0.302	0.393
38	0.088	0.115	0.145	0.180	0.226	0.293	0.382
40	0.086	0.113	0.142	0.175	0.220	0.285	0.371
42	0.084	0.110	0.139	0.171	0.214	0.278	0.361
44	0.082	0.108	0.136	0.167	0.209	0.271	0.352
46	0.080	0.105	0.133	0.164	0.204	0.264	0.344
48	0.079	0.103	0.130	0.160	0.199	0.258	0.336
50	0.077	0.101	0.128	0.157	0.195	0.253	0.328
52	0.076	0.099	0.126	0.154	0.191	0.247	0.321
54	0.074	0.097	0.123	0.151	0.187	0.243	0.315
56	0.073	0.096	0.121	0.148	0.184	0.238	0.309
58	0.072	0.094	0.119	0.146	0.181	0.233	0.303
60	0.071	0.092	0.117	0.143	0.177	0.229	0.297
62	0.070	0.091	0.116	0.141	0.174	0.225	0.292
64	0.068	0.089	0.114	0.139	0.171	0.221	0.287
66	0.067	0.088	0.112	0.137	0.169	0.218	0.282
68	0.066	0.087	0.111	0.135	0.166	0.214	0.278

TABLE VI. PERCENTAGE POINTS, ℓ_γ, SUCH THAT
$P\,[\hat{c}\ \ln(\hat{b}/b) < \ell_\gamma] = \gamma$ (Continued)

N \ γ	0.70	0.75	0.80	0.85	0.90	0.95	0.98
70	0.065	0.085	0.109	0.133	0.164	0.211	0.274
72	0.064	0.084	0.108	0.131	0.161	0.208	0.269
74	0.064	0.083	0.107	0.129	0.159	0.205	0.266
76	0.063	0.082	0.105	0.128	0.157	0.202	0.262
78	0.062	0.081	0.104	0.126	0.155	0.199	0.258
80	0.061	0.080	0.103	0.125	0.153	0.197	0.255
85	0.059	0.077	0.100	0.121	0.148	0.190	0.246
90	0.057	0.075	0.097	0.118	0.143	0.185	0.239
95	0.056	0.073	0.095	0.115	0.139	0.179	0.232
100	0.054	0.071	0.093	0.112	0.136	0.175	0.226
110	0.051	0.067	0.089	0.107	0.129	0.166	0.215
120	0.049	0.064	0.085	0.103	0.123	0.159	0.205

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING Z_a AND Z_b*

	n = 10							
p=r/n	1		7/10		5/10		2/10	
i	a_i	b_i	a_i	b_i	a_i	b_i	a_i	b_i
1	.03958	-.07107	-.00255	-.12531	-.08169	-.18478	-.67530	-.46452
2	.05108	-.07334	.01280	-.12299	-.05458	-.17371	1.67530	.46452
3	.06219	-.07177	.03094	-.11279	-.01793	-.14970		
4	.07342	-.06675	.05228	-.09525	.02859	-.11335		
5	.08512	-.05797	.07763	-.06949	1.12561	.62153		
6	.09767	-.04452	.10833	-.03336				
7	.11155	-.02459	.72057	.55919				
8	.12761	.00548						
9	.14751	.05431						
10	.20427	.35022						

*Reproduced from "An Exact Asymptotically Efficient Confidence Bound for Reliability in the Case of the Weibull Distribution," by M. V. Johns, Jr. and G. J. Lieberman, Technometrics, Vol. 8, No. 1, (1966), pp. 135-175.

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING Z_a AND Z_b (Continued)

n = 15

p=r/n	1		11/15		7/15		3/15	
i	a_i	b_i	a_i	b_i	a_i	b_i	a_i	b_i
1	.02383	-.04619	.00065	-.07776	-.07407	-.13306	-.47594	-.31963
2	.02932	-.04830	.00683	-.07905	-.06265	-.13055	-.41146	-.29297
3	.03452	-.04890	.01367	-.07754	-.04717	-.12274	1.88740	.61260
4	.03961	-.04832	.02120	-.07379	-.02811	-.11056		
5	.04471	-.04667	.02950	-.06793	-.00541	-.09416		
6	.04990	-.04392	.03871	-.05989	.02125	-.07332		
7	.05525	-.03996	.04899	-.04941	1.19616	.66438		
8	.06084	-.03461	.06059	-.03610				
9	.06677	-.02757	.07386	-.01931				
10	.07315	-.01835	.08930	.00194				
11	.08016	-.00619	.61672	.53884				
12	.08808	.01025						
13	.09740	.03359						
14	.10911	.06982						
15	.14734	.29532						

n = 20

p=r/n	1		15/20		10/20		5/20	
i	a_i	b_i	a_i	b_i	a_i	b_i	a_i	b_i
1	.01682	-.03402	.00120	-.05593	-.04527	-.09198	-.24498	-.19315
2	.02007	-.03564	.00456	-.05745	-.04032	-.09230	-.22587	-.18644
3	.02312	-.03645	.00816	-.05754	-.03371	-.09010	-.19843	-.17383
4	.02607	-.03667	.01201	-.05657	-.02574	-.08597	-.16426	-.15659
5	.02898	-.03639	.01612	-.05468	-.01650	-.08013	1.83354	-.71001
6	.03189	-.03563	.02053	-.05190	-.00596	-.07264		
7	.03482	-.03441	.02526	-.04822	.00595	-.06345		
8	.03780	-.03269	.03037	-.04361	.01935	-.05246		
9	.04086	-.03045	.03591	-.03798	.03444	-.03948		
10	.04401	-.02762	.04196	-.03119	1.10777	-.66851		
11	.04729	-.02411	.04862	-.02306				
12	.05074	-.01980	.05600	-.01336				
13	.05439	-.01451	.06428	-.00172				
14	.05830	-.00798	.07369	.01235				
15	.06257	.00016	.56132	.52087				
16	.06730	.01054						
17	.07268	.02419						
18	.07906	.04312						
19	.08714	.07197						
20	.11608	.25640						

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING Z_a AND Z_b (Continued)

n = 30

p=r/n	1		22/30		15/30		7/30	
i	a_i	b_i	a_i	b_i	a_i	b_i	a_i	b_i
1	.01046 -	.02215 -	.00105 -	.03780 -	.03092 -	.06072 -	.18830 -	.13857
2	.01201 -	.02314	.00042 -	.03893 -	.02916 -	.06164 -	.18110 -	.13688
3	.01345 -	.02379	.00198 -	.03944 -	.02675 -	.06151 -	.17012 -	.13259
4	.01483 -	.02419	.00363 -	.03951 -	.02385 -	.06063 -	.15631 -	.12611
5	.01618 -	.02440	.00536 -	.03923 -	.02052 -	.05914 -	.14008 -	.11862
6	.01751 -	.02445	.00718 -	.03863 -	.01679 -	.05710 -	.12169 -	.10937
7	.01882 -	.02434	.00910 -	.03775 -	.01267 -	.05453	1.95751	.76245
8	.02013 -	.02409	.01111 -	.03658 -	.00816 -	.05146		
9	.02145 -	.02369	.01323 -	.03513 -	.00325 -	.04788		
10	.02277 -	.02315	.01546 -	.03339	.00209 -	.04379		
11	.02411 -	.02246	.01781 -	.03137	.00787 -	.03915		
12	.02546 -	.02162	.02030 -	.02903	.01413 -	.03393		
13	.02684 -	.02062	.02294 -	.02636	.02092 -	.02811		
14	.02824 -	.01944	.02574 -	.02334	.02827 -	.02161		
15	.02969 -	.01807	.02873 -	.01992	1.09870 -	.68119		
16	.03117 -	.01648	.03192 -	.01607				
17	.03270 -	.01466	.03535 -	.01173				
18	.03428 -	.01257	.03904 -	.00683				
19	.03593 -	.01017	.04305	.00129				
20	.03767 -	.00740	.04743	.00500				
21	.03949 -	.00420	.05225	.01218				
22	.04143 -	.00047	.56902	.52514				
23	.04350	.00391						
24	.04574	.00913						
25	.04821	.01545						
26	.05096	.02331						
27	.05412	.03343						
28	.05789	.04719						
29	.06270	.06779						
30	.08227	.20535						

n = 50

p=r/n	1		37/50		25/50		12/50	
i	a_i	b_i	a_i	b_i	a_i	b_i	a_i	b_i
1	.00588 -	.01296 -	.00067 -	.02197 -	.01880 -	.03594 -	.10798 -	.08046
2	.00648 -	.01344 -	.00016 -	.02259 -	.01837 -	.03662 -	.10666 -	.08072
3	.00705 -	.01380	.00038 -	.02299 -	.01772 -	.03694 -	.10414 -	.08013
4	.00758 -	.01407	.00093 -	.02325 -	.01691 -	.03701 -	.10078 -	.07896
5	.00810 -	.01428	.00150 -	.02340 -	.01599 -	.03689 -	.09675 -	.07731
6	.00861 -	.01444	.00209 -	.02345 -	.01496 -	.03661 -	.09213 -	.07527
7	.00911 -	.01456	.00270 -	.02342 -	.01382 -	.03619 -	.08699 -	.07287
8	.00960 -	.01463	.00333 -	.02332 -	.01260 -	.03563 -	.08135 -	.07013

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING Z_a AND Z_b (Continued)

	n = 50							
p=r/n	1		37/50		25/50		12/50	
i	a_i	b_i	a_i	b_i	a_i	b_i	a_i	b_i
9	.01008 -	.01467	.00398 -	.02315 -	.01129 -	.03495 -	.07523 -	.06709
10	.01057 -	.01467	.00464 -	.02291 -	.00989 -	.03415 -	.06865 -	.06373
11	.01105 -	.01463	.00532 -	.02261 -	.00840 -	.03324 -	.06162 -	.06008
12	.01152 -	.01457	.00603 -	.02224 -	.00683 -	.03221	1.98227	.80675
13	.01200 -	.01447	.00675 -	.02182 -	.00517 -	.03107		
14	.01248 -	.01434	.00750 -	.02133 -	.00342 -	.02982		
15	.01296 -	.01418	.00827 -	.02079	.00158 -	.02846		
16	.01344 -	.01399	.00907 -	.02018	.00035 -	.02698		
17	.01393 -	.01376	.00989 -	.01951	.00238 -	.02538		
18	.01442 -	.01351	.01073 -	.01877	.00451 -	.02366		
19	.01491 -	.01321	.01161 -	.01796	.00675 -	.02181		
20	.01540 -	.01289	.01252 -	.01709	.00910 -	.01984		
21	.01591 -	.01252	.01345 -	.01614	.01156 -	.01772		
22	.01642 -	.01212	.01443 -	.01512	.01415 -	.01546		
23	.01693 -	.01168	.01544 -	.01401	.01687 -	.01305		
24	.01745 -	.01119	.01648 -	.01282	.01973 -	.01047		
25	.01798 -	.01067	.01757 -	.01154	1.09036	.69008		
26	.01852 -	.01009	.01871 -	.01017				
27	.01907 -	.00946	.01989 -	.00869				
28	.01964 -	.00877	.02113 -	.00709				
29	.02021 -	.00803	.02243 -	.00538				
30	.02080 -	.00722	.02379 -	.00354				
31	.02140 -	.00634	.02521 -	.00154				
32	.02202 -	.00538	.02672 -	.00060				
33	.02266 -	.00434	.02831 -	.00203				
34	.02332 -	.00319	.02999 -	.00545				
35	.02401 -	.00194	.03178	.00820				
36	.02471 -	.00057	.03369	.01119				
37	.02545	.00095	.53455	.51043				
38	.02623	.00263						
39	.02704	.00450						
40	.02789	.00659						
41	.02880	.00894						
42	.02977	.01163						
43	.03082	.01473						
44	.03196	.01834						
45	.03322	.02266						
46	.03464	.02793						
47	.03627	.03462						
48	.03823	.04360						
49	.04074	.05685						
50	.05269	.15062						

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING Z_a AND Z_b (Continued)

	n = 100							
p=r/n	1		75/100		50/100		25/100	
i	a_i	b_i	a_i	b_i	a_i	b_i	a_i	b_i
1	.00277 -	.00632 -	.00020 -	.01056 -	.00944 -	.01768 -	.04999 -	.03820
2	.00294 -	.00648 -	.00013 -	.01079 -	.00940 -	.01797 -	.05003 -	.03854
3	.00310 -	.00662 -	.00000 -	.01096 -	.00931 -	.01817 -	.04981 -	.03868
4	.00325 -	.00673	.00013 -	.01109 -	.00918 -	.01831 -	.04249 -	.03869
5	.00339 -	.00682	.00027 -	.01121 -	.00902 -	.01841 -	.04889 -	.03861
6	.00353 -	.00690	.00040 -	.01130 -	.00885 -	.01847 -	.04824 -	.03844
7	.00367 -	.00698	.00054 -	.01137 -	.00865 -	.01850 -	.04750 -	.03820
8	.00380 -	.00704	.00068 -	.01143 -	.00844 -	.01851 -	.04668 -	.03789
9	.00393 -	.00710	.00082 -	.11477 -	.00821 -	.01848 -	.04577 -	.03754
10	.00406 -	.00715	.00097 -	.01150 -	.00797 -	.01844 -	.04479 -	.03713
11	.00419 -	.00719	.00111 -	.01152 -	.00771 -	.01838 -	.04375 -	.03667
12	.00432 -	.00723	.00126 -	.01153 -	.00745 -	.01829 -	.04264 -	.03616
13	.00445 -	.00726	.00141 -	.01153 -	.00716 -	.01819 -	.04146 -	.03562
14	.00457 -	.00728	.00157 -	.01152 -	.00687 -	.01808 -	.04023 -	.03503
15	.00469 -	.00730	.00172 -	.01150 -	.00657 -	.01794 -	.03894 -	.03440
16	.00482 -	.00732	.00188 -	.01147 -	.00625 -	.01779 -	.03759 -	.03374
17	.00494 -	.00733	.00204 -	.01143 -	.00592 -	.01762 -	.03619 -	.03303
18	.00506 -	.00733	.00220 -	.01138 -	.00558 -	.01744 -	.03473 -	.03229
19	.00519 -	.00733	.00236 -	.01133 -	.00523 -	.01724 -	.03322 -	.03151
20	.00531 -	.00733	.00253 -	.01127 -	.00487 -	.01703 -	.03165 -	.03069
21	.00543 -	.00732	.00270 -	.01120 -	.00450 -	.01681 -	.03003 -	.02984
22	.00555 -	.00731	.00287 -	.01112 -	.00412 -	.01656 -	.02836 -	.02895
23	.00567 -	.00730	.00304 -	.01103 -	.00372 -	.01631 -	.02663 -	.02803
24	.00579 -	.00728	.00322 -	.01094 -	.00332 -	.01604 -	.02485 -	.02707
25	.00591 -	.00726	.00389 -	.01084 -	.00290 -	.01576	1.97141	.83495
26	.00603 -	.00723	.00357 -	.01073 -	.00248 -	.01546		
27	.00615 -	.00720	.00376 -	.01061 -	.00204 -	.01515		
28	.00627 -	.00716	.00394 -	.01049 -	.00159 -	.01482		
29	.00640 -	.00712	.00413 -	.01036 -	.00113 -	.01448		
30	.00652 -	.00708	.00432 -	.01022 -	.00065 -	.01412		
31	.00664 -	.00703	.00452 -	.01007 -	.00017 -	.01375		
32	.00676 -	.00698	.00472 -	.00992	.00033 -	.01337		
33	.00688 -	.00692	.00492 -	.00976	.00084 -	.01297		
34	.00701 -	.00686	.00512 -	.00959	.00137 -	.01255		
35	.00713 -	.00680	.00533 -	.00941	.00190 -	.01212		
36	.00725 -	.00673	.00544 -	.00922	.00245 -	.01167		
37	.00738 -	.00665	.00575 -	.00903	.00301 -	.01121		
38	.00750 -	.00658	.00597 -	.00882	.00359 -	.01073		
39	.00763 -	.00650	.00619 -	.00861	.00418 -	.01023		
40	.00775 -	.00611	.00642 -	.00839	.00479 -	.00971		

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING Z_a AND Z_b (Continued)

	n = 100							
p=r/n	1		75/100		50/100		25/100	
i	a_i	b_i	a_i	b_i	a_i	b_i	a_i	b_i
41	.00788	- .00632	.00664	- .00816	.00541	- .00918		
42	.00801	- .00622	.00688	- .00792	.00695	- .00863		
43	.00813	- .00612	.00711	- .00767	.00670	- .00806		
44	.00826	- .00601	.00736	- .00741	.00737	- .00747		
45	.00839	- .00590	.00760	- .00714	.00805	- .00687		
46	.00852	- .00579	.00785	- .00686	.00875	- .00624		
47	.00866	- .00566	.00811	- .00657	.00948	- .00559		
48	.00879	- .00554	.00837	- .00627	.01022	- .00492		
49	.00892	- .00540	.00863	- .00595	.01097	- .00422		
50	.00906	- .00526	.00890	- .00563	1.08321	.69595		
51	.00919	- .00512	.00918	- .00529				
52	.00933	- .00497	.00946	- .00494				
53	.00947	- .00481	.00975	- .00458				
54	.00961	- .00464	.01005	- .00420				
55	.00975	- .00447	.01035	- .00381				
56	.00990	- .00429	.01065	- .00340				
57	.01004	- .00410	.01097	- .00298				
58	.01019	- .00390	.01129	- .00255				
59	.01034	- .00370	.01162	- .00209				
60	.01049	- .00348	.01196	- .00162				
61	.01064	- .00326	.01231	- .00113				
62	.01080	- .00303	.01266	- .00062				
63	.01095	- .00278	.01303	- .00009				
64	.01111	- .00253	.01341	.00046				
65	.01127	- .00226	.01379	.00104				
66	.01144	- .00199	.01419	.00163				
67	.01160	- .00170	.01460	.00226				
68	.01177	- .00139	.01502	.00291				
69	.01195	- .00107	.01546	.00359				
70	.01212	- .00074	.01591	.00429				
71	.01230	- .00039	.01637	.00504				
72	.01240	- .00002	.01685	.00581				
73	.01267	.00037	.01735	.00663				
74	.01287	.00077	.01786	.00748				
75	.01306	.00120	.49752	.49223				
76	.01326	.00165						
77	.01347	.00213						

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING Z_a AND Z_b (Continued)

	n = 100							
p=r/n	1		75/100		80/100		25/100	
i	a_i	b_i	a_i	b_i	a_i	b_i	a_i	b_i
78	.01368	.00264						
79	.01390	.00317						
80	.01412	.00374						
81	.01436	.00435						
82	.01459	.00500						
83	.01484	.00569						
84	.01510	.00643						
85	.01537	.00723						
86	.01565	.00810						
87	.01594	.00904						
88	.01625	.01006						
89	.01657	.01119						
90	.01692	.01243						
91	.01728	.01382						
92	.01768	.01538						
93	.01810	.01716						
94	.01857	.01922						
95	.01908	.02164						
96	.01967	.02458						
97	.02034	.02826						
98	.02115	.03314						
99	.02220	.01027						
100	.02829	.09493						

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$*

	$n = 10$, $p = r/n = 2/10$				
	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.726	.543	.319	.154	.010
.1	.734	.564	.357	.193	.022
.2	.742	.585	.381	.224	.045
.3	.749	.599	.409	.274	.072
.4	.755	.614	.439	.314	.104
.5	.763	.626	.469	.345	.135
.6	.773	.647	.493	.385	.169
.7	.780	.660	.520	.423	.224
.8	.789	.677	.539	.450	.256
.9	.797	.690	.560	.477	.304
1.0	.806	.702	.585	.508	.338
1.1	.814	.717	.601	.538	.412
1.2	.822	.725	.614	.556	.428
1.3	.828	.738	.634	.578	.467
1.4	.835	.751	.648	.594	.484
1.5	.842	.759	.661	.609	.501
1.6	.848	.769	.672	.618	.514
1.7	.855	.778	.685	.626	.526
1.8	.860	.785	.694	.639	.541
1.9	.865	.793	.708	.645	.545
2.0	.873	.800	.717	.652	.554
2.1	.878	.806	.722	.659	.562
2.2	.883	.811	.731	.670	.569
2.3	.888	.815	.738	.675	.572
2.4	.892	.821	.743	.686	.578
2.5	.897	.829	.746	.688	.578
2.6	.900	.833	.751	.691	.586
2.7	.903	.838	.757	.694	.589
2.8	.907	.842	.760	.700	.595
2.9	.912	.849	.767	.707	.596
3.0	.915	.853	.773	.711	.597
3.1	.918	.855	.779	.714	.600
3.2	.921	.859	.784	.717	.605
3.3	.924	.863	.786	.721	.609
3.4	.926	.865	.791	.724	.609
3.5	.928	.869	.796	.728	.609
3.6	.930	.870	.798	.732	.609
3.7	.932	.873	.800	.736	.609

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

*Reproduced from "An Exact Asymptotically Efficient Confidence Bound for Reliability in the Case of the Weibull Distribution," by M. V. Johns, Jr. and G. J. Lieberman, Technometrics, Vol. 8, No. 1, (1966), pp. 135-175.

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 10$
$p = r/n = 2/10$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.8	.934	.875	.804	.740	.609
3.9	.937	.879	.807	.745	.611
4.0	.939	.880	.809	.748	.613
4.1	.941	.883	.810	.752	.616
4.2	.944	.887	.813	.753	.617
4.3	.946	.890	.816	.754	.617
4.4	.948	.892	.818	.755	.618
4.5	.950	.894	.820	.756	.622
4.6	.951	.896	.823	.759	.623
4.7	.953	.899	.825	.762	.623
4.8	.955	.900	.826	.764	.623
4.9	.957	.901	.830	.766	.626
5.0	.959	.902	.833	.769	.628

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 10$
$p = r/n = 5/10$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.464	.341	.244	.193	.095
.1	.490	.374	.281	.234	.126
.2	.516	.403	.315	.270	.153
.3	.543	.434	.350	.304	.180
.4	.568	.466	.381	.334	.217
.5	.593	.493	.410	.357	.236
.6	.617	.518	.436	.386	.269
.7	.640	.542	.462	.413	.300
.8	.663	.568	.484	.430	.327
.9	.684	.589	.508	.455	.352
1.0	.703	.611	.531	.475	.378
1.1	.720	.633	.543	.495	.404
1.2	.738	.653	.564	.513	.426
1.3	.766	.674	.581	.526	.440
1.4	.771	.692	.599	.540	.453
1.5	.789	.707	.616	.557	.467
1.6	.805	.719	.631	.573	.486
1.7	.817	.731	.643	.589	.495
1.8	.829	.745	.657	.603	.505
1.9	.840	.759	.670	.618	.518
2.0	.850	.773	.683	.630	.530
2.1	.859	.784	.696	.642	.538
2.2	.868	.794	.707	.651	.551
2.3	.877	.804	.720	.662	.561
2.4	.885	.815	.733	.671	.568
2.5	.892	.824	.742	.678	.576
2.6	.899	.832	.750	.687	.592
2.7	.906	.843	.760	.696	.606
2.8	.912	.850	.771	.707	.616
2.9	.919	.858	.780	.718	.627
3.0	.924	.864	.789	.724	.634
3.1	.929	.870	.797	.730	.640
3.2	.934	.878	.806	.736	.646
3.3	.939	.885	.813	.743	.652
3.4	.942	.891	.820	.751	.657
3.5	.946	.896	.826	.756	.663
3.6	.950	.901	.834	.762	.669
3.7	.953	.906	.841	.767	.675
3.8	.956	.911	.846	.775	.681

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 10$

$p = r/n = 5/10$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.960	.916	.850	.783	.687
4.0	.963	.921	.855	.789	.693
4.1	.965	.925	.862	.795	.699
4.2	.968	.929	.867	.801	.704
4.3	.970	.932	.872	.806	.710
4.4	.972	.935	.877	.812	.716
4.5	.974	.939	.883	.818	.721
4.6	.975	.942	.887	.823	.727
4.7	.977	.944	.891	.828	.732
4.8	.978	.947	.896	.834	.738
4.9	.980	.950	.899	.839	.744
5.0	.981	.953	.903	.843	.750

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 10$
$p = r/n = 7/10$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.415	.332	.260	.215	.141
.1	.448	.362	.290	.245	.163
.2	.480	.396	.323	.275	.191
.3	.509	.423	.351	.302	.214
.4	.537	.453	.380	.328	.243
.5	.567	.482	.402	.357	.271
.6	.595	.509	.426	.387	.304
.7	.620	.535	.452	.408	.322
.8	.645	.560	.475	.425	.340
.9	.668	.582	.493	.447	.359
1.0	.691	.607	.514	.469	.377
1.1	.712	.629	.537	.491	.402
1.2	.730	.650	.555	.508	.420
1.3	.747	.669	.578	.522	.435
1.4	.767	.687	.595	.537	.453
1.5	.784	.704	.612	.554	.467
1.6	.800	.722	.630	.570	.485
1.7	.814	.736	.645	.583	.500
1.8	.827	.752	.659	.599	.514
1.9	.840	.765	.672	.615	.529
2.0	.852	.779	.687	.628	.543
2.1	.862	.791	.702	.645	.556
2.2	.873	.804	.714	.660	.567
2.3	.883	.813	.727	.674	.576
2.4	.892	.824	.741	.684	.583
2.5	.900	.835	.752	.697	.590
2.6	.908	.845	.763	.710	.597
2.7	.915	.855	.773	.717	.604
2.8	.921	.863	.782	.727	.615
2.9	.927	.871	.792	.738	.626
3.0	.932	.879	.802	.748	.634
3.1	.937	.886	.811	.758	.640
3.2	.942	.892	.819	.768	.651
3.3	.947	.899	.830	.778	.662
3.4	.951	.905	.837	.787	.674
3.5	.955	.910	.845	.795	.684
3.6	.958	.916	.853	.804	.698
3.7	.962	.921	.860	.813	.702
3.8	.965	.926	.866	.821	.709

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 10$
$p = r/n = 7/10$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.968	.930	.873	.827	.715
4.0	.970	.934	.878	.836	.722
4.1	.973	.939	.883	.845	.730
4.2	.975	.943	.888	.851	.737
4.3	.977	.946	.893	.856	.744
4.4	.979	.949	.898	.861	.750
4.5	.980	.952	.904	.866	.755
4.6	.982	.955	.908	.870	.759
4.7	.983	.958	.911	.875	.764
4.8	.985	.960	.915	.880	.770
4.9	.986	.963	.919	.884	.778
5.0	.987	.965	.924	.889	.785

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 10
p = r/n = 1

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.393	.315	.255	.212	.153
.1	.428	.345	.283	.238	.176
.2	.458	.376	.311	.264	.202
.3	.492	.409	.336	.291	.226
.4	.522	.442	.363	.319	.247
.5	.552	.474	.389	.345	.273
.6	.581	.502	.416	.371	.298
.7	.607	.527	.439	.396	.317
.8	.634	.553	.464	.421	.334
.9	.658	.579	.490	.442	.352
1.0	.682	.605	.512	.463	.369
1.1	.705	.627	.535	.485	.395
1.2	.726	.649	.559	.505	.421
1.3	.747	.670	.582	.525	.445
1.4	.768	.690	.605	.546	.462
1.5	.786	.707	.621	.567	.478
1.6	.800	.725	.644	.587	.494
1.7	.816	.742	.662	.603	.506
1.8	.830	.758	.680	.622	.522
1.9	.843	.772	.697	.636	.540
2.0	.855	.787	.710	.654	.559
2.1	.868	.801	.727	.668	.573
2.2	.879	.814	.743	.684	.587
2.3	.889	.826	.758	.700	.600
2.4	.898	.837	.772	.713	.613
2.5	.907	.847	.783	.725	.626
2.6	.915	.856	.795	.738	.639
2.7	.921	.865	.806	.751	.651
2.8	.928	.874	.816	.762	.665
2.9	.934	.883	.826	.775	.677
3.0	.939	.890	.835	.787	.689
3.1	.944	.898	.846	.800	.698
3.2	.949	.904	.853	.811	.708
3.3	.954	.911	.861	.820	.719
3.4	.957	.917	.868	.827	.729
3.5	.961	.922	.875	.837	.739
3.6	.964	.927	.883	.846	.748
3.7	.968	.933	.889	.854	.757
3.8	.970	.937	.895	.862	.766

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 10

p = r/n = 1

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.973	.941	.901	.869	.775
4.0	.975	.945	.906	.875	.784
4.1	.977	.949	.912	.880	.792
4.2	.979	.952	.917	.885	.800
4.3	.981	.956	.922	.892	.808
4.4	.982	.959	.926	.896	.815
4.5	.984	.962	.931	.903	.822
4.6	.985	.964	.935	.907	.827
4.7	.987	.967	.939	.912	.833
4.8	.988	.969	.943	.916	.838
4.9	.989	.972	.946	.921	.843
5.0	.990	.974	.950	.925	.848

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 15$
$p = r/n = 3/15$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.646	.443	.210	.090	.001
.1	.660	.475	.242	.118	.006
.2	.673	.508	.276	.160	.017
.3	.688	.534	.318	.194	.037
.4	.702	.561	.357	.240	.064
.5	.716	.583	.392	.285	.101
.6	.732	.607	.433	.331	.147
.7	.742	.627	.478	.382	.202
.8	.755	.647	.520	.428	.257
.9	.766	.665	.553	.465	.300
1.0	.776	.681	.584	.495	.348
1.1	.787	.698	.610	.533	.395
1.2	.799	.715	.631	.559	.451
1.3	.812	.733	.651	.591	.491
1.4	.821	.749	.671	.619	.522
1.5	.832	.762	.691	.642	.547
1.6	.840	.773	.707	.658	.566
1.7	.849	.785	.725	.673	.587
1.8	.857	.797	.736	.684	.604
1.9	.866	.806	.744	.697	.609
2.0	.873	.814	.751	.707	.620
2.1	.879	.823	.761	.718	.642
2.2	.886	.829	.768	.729	.654
2.3	.893	.839	.774	.739	.661
2.4	.900	.846	.782	.749	.676
2.5	.905	.853	.791	.757	.688
2.6	.911	.859	.798	.763	.699
2.7	.914	.864	.805	.772	.704
2.8	.919	.869	.814	.776	.707
2.9	.923	.874	.819	.784	.709
3.0	.927	.879	.824	.790	.711
3.1	.932	.883	.829	.794	.717
3.2	.936	.887	.832	.799	.720
3.3	.939	.891	.836	.802	.723
3.4	.942	.896	.842	.803	.726
3.5	.945	.899	.849	.810	.733
3.6	.948	.902	.852	.819	.735
3.7	.951	.906	.857	.822	.736
3.6	.953	.910	.860	.825	.738

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 15$
$p = r/n = 3/15$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.955	.914	.863	.828	.741
4.0	.957	.917	.865	.832	.743
4.1	.960	.919	.868	.835	.745
4.2	.962	.921	.871	.837	.745
4.3	.964	.924	.875	.841	.746
4.4	.966	.927	.878	.843	.748
4.5	.968	.929	.880	.846	.749
4.6	.969	.932	.884	.849	.752
4.7	.971	.934	.888	.853	.757
4.8	.972	.936	.890	.857	.763
4.9	.974	.938	.892	.860	.768
5.0	.975	.939	895	.862	.769

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

	n = 15 p = r/n = 7/15				
	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.443	.343	.247	.205	.111
.1	.471	.373	.284	.245	.149
.2	.502	.404	.320	.280	.197
.3	.530	.438	.356	.317	.243
.4	.560	.472	.391	.351	.285
.5	.586	.500	.427	.385	.318
.6	.615	.528	.457	.417	.344
.7	.639	.556	.486	.446	.381
.8	.661	.582	.514	.470	.403
.9	.684	.608	.542	.496	.421
1.0	.705	.630	.562	.521	.444
1.1	.725	.653	.587	.548	.466
1.2	.743	.672	.606	.567	.487
1.3	.760	.690	.626	.585	.502
1.4	.776	.710	.646	.604	.516
1.5	.794	.729	.664	.624	.530
1.6	.809	.743	.677	.642	.543
1.7	.823	.759	.690	.658	.564
1.8	.835	.773	.706	.673	.579
1.9	.846	.786	.719	.689	.592
2.0	.857	.799	.732	.702	.610
2.1	.868	.810	.744	.715	.627
2.2	.877	.822	.757	.725	.642
2.3	.886	.832	.768	.735	.658
2.4	.895	.841	.779	.744	.670
2.5	.902	.851	.788	.755	.680
2.6	.910	.859	.799	.764	.689
2.7	.916	.866	.810	.774	.697
2.8	.922	.873	.819	.783	.707
2.9	.928	.881	.827	.791	.719
3.0	.933	.889	.836	.798	.731
3.1	.938	.895	.844	.806	.743
3.2	.943	.901	.851	.815	.754
3.3	.948	.906	.857	.822	.760
3.4	.952	.911	.864	.828	.765
3.5	.955	.916	.870	.836	.770
3.6	.958	.920	.876	.843	.775
3.7	.962	.925	.882	.851	.780
3.8	.965	.929	.888	.857	.784

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 15$
$p = r/n = 7/15$

Z_a/Z_b	$\gamma = 0.50$ $L^*(Z_a/Z_b)$	$\gamma = 0.75$ $L^*(Z_a/Z_b)$	$\gamma = 0.90$ $L^*(Z_a/Z_b)$	$\gamma = 0.95$ $L^*(Z_a/Z_b)$	$\gamma = 0.99$ $L^*(Z_a/Z_b)$
3.9	.967	.933	.894	.862	.789
4.0	.969	.937	.898	.867	.795
4.1	.972	.940	.902	.872	.801
4.2	.974	.944	.907	.876	.808
4.3	.976	.947	.911	.882	.814
4.4	.978	.949	.915	.886	.821
4.5	.979	.952	.919	.891	.827
4.6	.981	.955	.922	.896	.834
4.7	.982	.958	.926	.900	.840
4.8	.984	.960	.929	.905	.845
4.9	.985	.963	.932	.908	.850
5.0	.986	.965	.935	.912	.852

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 15$

$p = r/n = 11/15$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.401	.328	.269	.233	.179
.1	.433	.362	.304	.262	.207
.2	.467	.395	.335	.297	.233
.3	.499	.427	.369	.325	.264
.4	.530	.458	.400	.355	.295
.5	.559	.488	.430	.383	.318
.6	.587	.516	.457	.412	.340
.7	.614	.544	.485	.440	.363
.8	.641	.573	.512	.468	.388
.9	.664	.598	.535	.492	.413
1.0	.688	.624	.557	.518	.434
1.1	.712	.646	.578	.539	.450
1.2	.732	.667	.599	.559	.469
1.3	.752	.685	.622	.580	.490
1.4	.772	.705	.642	.601	.510
1.5	.790	.724	.659	.620	.527
1.6	.807	.742	.676	.639	.539
1.7	.823	.759	.691	.657	.560
1.8	.837	.775	.707	.672	.580
1.9	.851	.790	.721	.687	.599
2.0	.862	.805	.736	.700	.618
2.1	.873	.818	.752	.716	.634
2.2	.883	.830	.765	.729	.645
2.3	.892	.842	.779	.742	.663
2.4	.901	.852	.792	.755	.675
2.5	.909	.861	.803	.768	.687
2.6	.917	.870	.813	.779	.702
2.7	.924	.879	.823	.790	.712
2.8	.930	.887	.832	.801	.722
2.9	.936	.896	.842	.812	.734
3.0	.941	.903	.852	.822	.746
3.1	.946	.910	.861	.829	.758
3.2	.951	.916	.869	.837	.769
3.3	.955	.922	.877	.845	.779
3.4	.958	.927	.883	.853	.789
3.5	.962	.932	.890	.861	.798
3.6	.965	.936	.896	.869	.806
3.7	.968	.941	.901	.875	.813
3.8	.971	.945	.907	.882	.819

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 15$

$p = r/n = 11/15$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.973	.949	.912	.888	.825
4.0	.976	.953	.917	.893	.831
4.1	.978	.956	.922	.898	.837
4.2	.980	.959	.927	.903	.846
4.3	.981	.962	.932	.907	.854
4.4	.983	.965	.936	.911	.862
4.5	.984	.967	.939	.916	.870
4.6	.985	.969	.942	.920	.877
4.7	.987	.971	.946	.923	.882
4.8	.988	.973	.949	.928	.887
4.9	.989	.975	.952	.932	.892
5.0	.990	.977	.955	.936	.896

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 15$

$p = r/n = 1$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.388	.321	.271	.234	.180
.1	.422	.355	.302	.261	.207
.2	.455	.388	.334	.286	.235
.3	.488	.419	.365	.317	.267
.4	.521	.452	.393	.345	.291
.5	.552	.482	.422	.376	.314
.6	.580	.513	.450	.403	.336
.7	.610	.540	.478	.430	.362
.8	.638	.568	.505	.461	.390
.9	.664	.595	.531	.489	.411
1.0	.688	.620	.556	.515	.428
1.1	.712	.645	.581	.539	.454
1.2	.734	.668	.602	.565	.471
1.3	.754	.690	.623	.588	.495
1.4	.773	.711	.643	.612	.518
1.5	.791	.731	.663	.631	.539
1.6	.808	.748	.683	.653	.555
1.7	.823	.765	.701	.670	.571
1.8	.836	.781	.720	.687	.587
1.9	.851	.797	.738	.704	.605
2.0	.864	.813	.755	.719	.623
2.1	.875	.826	.770	.732	.640
2.2	.885	.839	.784	.747	.658
2.3	.895	.850	.798	.762	.673
2.4	.904	.861	.809	.776	.688
2.5	.912	.871	.823	.787	.703
2.6	.920	.880	.835	.799	.718
2.7	.927	.889	.845	.810	.732
2.8	.933	.897	.855	.821	.745
2.9	.939	.906	.865	.831	.758
3.0	.945	.912	.873	.840	.770
3.1	.950	.919	.882	.849	.782
3.2	.954	.925	.890	.857	.793
3.3	.958	.931	.897	.865	.802
3.4	.962	.936	.904	.874	.812
3.5	.966	.940	.910	.881	.822
3.6	.968	.945	.916	.888	.830
3.7	.971	.949	.922	.895	.836
3.8	.974	.953	.927	.900	.844

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 15$
$p = r/n = 1$

Z_a/Z_b	$\gamma = 0.50$ $L^*(Z_a/Z_b)$	$\gamma = 0.75$ $L^*(Z_a/Z_b)$	$\gamma = 0.90$ $L^*(Z_a/Z_b)$	$\gamma = 0.95$ $L^*(Z_a/Z_b)$	$\gamma = 0.99$ $L^*(Z_a/Z_b)$
3.9	.976	.957	.932	.906	.854
4.0	.978	.960	.936	.911	.863
4.1	.980	.963	.941	.916	.871
4.2	.982	.966	.945	.921	.878
4.3	.984	.969	.949	.926	.884
4.4	.985	.971	.952	.931	.887
4.5	.986	.973	.956	.935	.890
4.6	.988	.975	.959	.939	.893
4.7	.989	.977	.962	.942	.896
4.8	.990	.979	.964	.945	.899
4.9	.991	.980	.966	.949	.902
5.0	.992	.982	.968	.952	.907

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 20
p = r/n = 5/20

	γ = 0.50	γ = 0.75	γ = 0.90	γ = 0.95	γ = 0.99
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.523	.350	.188	.105	.008
.1	.544	.387	.228	.140	.020
.2	.569	.423	.271	.186	.037
.3	.596	.459	.305	.231	.068
.4	.620	.491	.343	.274	.118
.5	.642	.524	.385	.317	.164
.6	.663	.552	.427	.360	.229
.7	.683	.582	.465	.401	.287
.8	.704	.610	.501	.439	.331
.9	.720	.640	.539	.477	.380
1.0	.735	.665	.570	.519	.430
1.1	.754	.687	.601	.552	.464
1.2	.768	.706	.631	.583	.484
1.3	.783	.724	.656	.614	.519
1.4	.796	.742	.679	.637	.538
1.5	.809	.758	.698	.659	.559
1.6	.824	.775	.718	.674	.587
1.7	.835	.790	.735	.697	.609
1.8	.846	.802	.746	.713	.628
1.9	.858	.813	.761	.728	.644
2.0	.868	.823	.773	.741	.665
2.1	.878	.834	.785	.753	.677
2.2	.887	.842	.797	.762	.687
2.3	.895	.850	.807	.773	.695
2.4	.903	.857	.817	.781	.702
2.5	.909	.865	.824	.791	.713
2.6	.916	.873	.831	.798	.720
2.7	.922	.879	.837	.803	.726
2.8	.928	.885	.843	.809	.733
2.9	.933	.891	.851	.815	.745
3.0	.938	.896	.857	.823	.752
3.1	.942	.902	.865	.826	.755
3.2	.946	.907	.870	.833	.763
3.3	.950	.912	.875	.830	.768
3.4	.953	.917	.880	.844	.773
3.5	.956	.921	.885	.850	.779
3.6	.959	.925	.889	.854	.784
3.7	.962	.929	.893	.858	.788
3.8	.965	.933	.898	.862	.793

$L^*(Z_a/Z_b)$ is the exact ower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 20$
$p = r/n = 5/20$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.967	.936	.902	.866	.797
4.0	.969	.939	.905	.870	.802
4.1	.971	.942	.909	.873	.806
4.2	.973	.945	.912	.878	.810
4.3	.975	.948	.915	.880	.815
4.4	.977	.951	.919	.883	.819
4.5	.978	.954	.922	.886	.824
4.6	.980	.957	.924	.889	.828
4.7	.981	.959	.927	.893	.832
4.8	.983	.962	.931	.898	.836
4.9	.984	.963	.933	.902	.839
5.0	.985	.965	.936	.904	.843

$L^*(Z_a/Z_b)$ is the exact ower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 20$

$p = r/n = 10/20$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.415	.333	.257	.224	.141
.1	.446	.369	.294	.263	.180
.2	.479	.405	.332	.297	.222
.3	.509	.441	.365	.332	.264
.4	.542	.472	.402	.367	.290
.5	.573	.502	.436	.401	.336
.6	.604	.530	.468	.432	.370
.7	.632	.559	.497	.461	.404
.8	.657	.588	.530	.492	.432
.9	.681	.614	.559	.520	.453
1.0	.704	.637	.584	.546	.474
1.1	.725	.659	.608	.571	.495
1.2	.746	.680	.633	.591	.516
1.3	.764	.701	.652	.614	.534
1.4	.780	.721	.672	.637	.546
1.5	.796	.740	.691	.657	.564
1.6	.811	.758	.707	.673	.588
1.7	.824	.773	.721	.692	.607
1.8	.837	.790	.737	.710	.628
1.9	.850	.804	.751	.723	.646
2.0	.862	.817	.764	.737	.660
2.1	.872	.829	.777	.750	.671
2.2	.882	.840	.789	.761	.681
2.3	.892	.850	.801	.772	.692
2.4	.900	.860	.812	.782	.702
2.5	.909	.869	.823	.793	.712
2.6	.916	.878	.832	.804	.722
2.7	.922	.887	.842	.815	.731
2.8	.929	.894	.851	.821	.740
2.9	.935	.901	.859	.830	.749
3.0	.940	.907	.868	.839	.758
3.1	.945	.913	.875	.848	.766
3.2	.950	.918	.883	.855	.774
3.3	.954	.924	.890	.862	.782
3.4	.958	.929	.896	.869	.792
3.5	.962	.933	.902	.875	.801
3.6	.965	.938	.908	.881	.809
3.7	.968	.942	.913	.887	.817
3.8	.970	.946	.918	.892	.825

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

	$n = 20$ $p = r/n = 10/20$				
	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.973	.949	.923	.898	.833
4.0	.975	.953	.928	.903	.840
4.1	.977	.956	.932	.908	.848
4.2	.979	.959	.936	.912	.854
4.3	.981	.961	.939	.916	.860
4.4	.982	.964	.943	.920	.864
4.5	.984	.967	.946	.925	.868
4.6	.985	.969	.949	.929	.871
4.7	.987	.971	.952	.933	.875
4.8	.988	.973	.955	.936	.879
4.9	.989	.975	.957	.940	.882
5.0	.990	.976	.960	.943	.886

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 20$
$p = r/n = 15/20$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.390	.332	.278	.240	.192
.1	.424	.367	.310	.272	.221
.2	.457	.400	.342	.306	.253
.3	.492	.433	.374	.338	.279
.4	.524	.466	.408	.373	.307
.5	.558	.496	.438	.408	.332
.6	.589	.523	.466	.439	.361
.7	.617	.550	.497	.466	.387
.8	.645	.575	.528	.489	.412
.9	.671	.603	.554	.516	.436
1.0	.697	.629	.580	.540	.459
1.1	.720	.655	.605	.565	.482
1.2	.741	.676	.629	.589	.503
1.3	.761	.698	.649	.612	.524
1.4	.780	.719	.668	.634	.544
1.5	.797	.737	.687	.654	.564
1.6	.812	.756	.705	.672	.584
1.7	.827	.772	.723	.690	.603
1.8	.840	.788	.739	.707	.621
1.9	.853	.803	.755	.723	.639
2.0	.866	.816	.770	.738	.656
2.1	.877	.830	.784	.753	.670
2.2	.887	.842	.797	.765	.688
2.3	.896	.854	.810	.778	.704
2.4	.905	.864	.821	.792	.719
2.5	.913	.875	.832	.805	.733
2.6	.920	.883	.842	.817	.746
2.7	.927	.892	.851	.826	.757
2.8	.933	.899	.860	.835	.769
2.9	.939	.907	.869	.845	.780
3.0	.944	.914	.877	.856	.790
3.1	.949	.920	.884	.863	.800
3.2	.953	.925	.891	.870	.809
3.3	.958	.930	.898	.877	.818
3.4	.961	.936	.905	.884	.827
3.5	.964	.940	.911	.890	.835
3.6	.967	.945	.916	.895	.843
3.7	.970	.949	.921	.902	.851
3.8	.973	.953	.927	.908	.858

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

	n = 20 p = r/n = 15/20 $\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.975	.956	.932	.914	.865
4.0	.977	.960	.936	.919	.872
4.1	.979	.963	.939	.923	.878
4.2	.981	.966	.943	.928	.884
4.3	.983	.968	.947	.931	.890
4.4	.985	.971	.950	.935	.895
4.5	.986	.973	.954	.939	.900
4.6	.987	.975	.957	.942	.904
4.7	.988	.977	.959	.945	.907
4.8	.989	.979	.962	.948	.910
4.9	.990	.980	.964	.951	.915
5.0	.991	.982	.967	.954	.919

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

	$n = 20$	$p = r/n = 1$			
	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.380	.328	.278	.249	.202
.1	.416	.363	.309	.283	.228
.2	.451	.395	.338	.313	.256
.3	.487	.429	.370	.348	.281
.4	.519	.462	.403	.379	.312
.5	.553	.491	.433	.406	.338
.6	.586	.521	.464	.434	.364
.7	.613	.548	.494	.461	.388
.8	.642	.575	.525	.490	.413
.9	.668	.603	.552	.514	.436
1.0	.693	.629	.579	.541	.462
1.1	.717	.654	.605	.568	.486
1.2	.740	.679	.628	.593	.510
1.3	.761	.700	.649	.615	.533
1.4	.781	.722	.670	.636	.557
1.5	.799	.742	.692	.657	.579
1.6	.816	.761	.713	.680	.600
1.7	.831	.779	.732	.700	.621
1.8	.846	.795	.748	.721	.640
1.9	.859	.810	.763	.737	.661
2.0	.871	.824	.778	.755	.681
2.1	.883	.837	.792	.768	.700
2.2	.893	.849	.806	.785	.719
2.3	.902	.861	.819	.798	.732
2.4	.911	.872	.830	.811	.745
2.5	.919	.881	.842	.823	.758
2.6	.926	.890	.852	.834	.772
2.7	.933	.898	.863	.844	.785
2.8	.939	.906	.873	.854	.796
2.9	.944	.914	.881	.862	.807
3.0	.949	.920	.889	.872	.817
3.1	.954	.926	.896	.881	.827
3.2	.958	.932	.904	.888	.836
3.3	.962	.938	.911	.895	.844
3.4	.965	.943	.917	.901	.853
3.5	.969	.947	.923	.907	.861
3.6	.971	.951	.928	.914	.869
3.7	.974	.955	.933	.920	.877
3.8	.976	.959	.938	.925	.885

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 20$

$p = r/n = 1$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.979	.962	.942	.930	.893
4.0	.981	.965	.947	.935	.898
4.1	.982	.968	.951	.939	.903
4.2	.984	.971	.954	.943	.908
4.3	.985	.973	.957	.947	.913
4.4	.987	.975	.960	.950	.918
4.5	.988	.977	.963	.953	.923
4.6	.989	.979	.966	.956	.927
4.7	.990	.981	.968	.959	.931
4.8	.991	.982	.970	.962	.935
4.9	.992	.984	.972	.964	.938
5.0	.993	.985	.974	.967	.942

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 30$
$p = r/n = 7/30$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.485	.335	.198	.104	.015
.1	.512	.372	.238	.136	.033
.2	.542	.408	.282	.179	.060
.3	.567	.442	.323	.220	.098
.4	.592	.477	.367	.268	.143
.5	.615	.513	.408	.322	.188
.6	.637	.543	.449	.361	.237
.7	.661	.576	.486	.409	.289
.8	.683	.604	.520	.456	.346
.9	.705	.630	.555	.501	.397
1.0	.723	.656	.590	.544	.442
1.1	.742	.681	.619	.577	.482
1.2	.759	.704	.643	.604	.515
1.3	.776	.726	.669	.631	.552
1.4	.793	.745	.688	.655	.589
1.5	.809	.761	.711	.676	.608
1.6	.823	.777	.729	.694	.633
1.7	.836	.794	.746	.716	.659
1.8	.847	.807	.761	.735	.669
1.9	.858	.819	.774	.752	.691
2.0	.869	.831	.787	.765	.712
2.1	.878	.841	.799	.777	.732
2.2	.887	.851	.810	.787	.741
2.3	.895	.860	.820	.798	.750
2.4	.903	.869	.829	.809	.762
2.5	.911	.877	.839	.820	.773
2.6	.918	.885	.846	.829	.783
2.7	.925	.892	.855	.835	.791
2.8	.930	.898	.862	.843	.800
2.9	.935	.903	.868	.851	.809
3.0	.940	.909	.874	.857	.816
3.1	.945	.914	.881	.864	.824
3.2	.948	.920	.886	.869	.831
3.3	.952	.925	.892	.874	.838
3.4	.956	.929	.896	.878	.842
3.5	.959	.933	.901	.882	.846
3.6	.962	.938	.907	.886	.849
3.7	.965	.941	.911	.891	.855
3.8	.968	.945	.916	.895	.860

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 30
p = r/n = 7/30

	γ = 0.50	γ = 0.75	γ = 0.90	γ = 0.95	γ = 0.99
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.970	.948	.920	.898	.865
4.0	.972	.951	.923	.902	.870
4.1	.974	.954	.926	.906	.875
4.2	.977	.957	.929	.910	.879
4.3	.978	.960	.932	.914	.882
4.4	.980	.962	.935	.918	.885
4.5	.981	.964	.939	.920	.886
4.6	.983	.966	.942	.923	.888
4.7	.984	.968	.944	.925	.890
4.8	.985	.970	.946	.928	.892
4.9	.986	.972	.949	.931	.894
5.0	.988	.974	.951	.933	.895

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

			n = 30 p = r/n = 15/30		
	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.399	.329	.269	.230	.169
.1	.432	.369	.303	.270	.212
.2	.464	.402	.341	.309	.252
.3	.496	.437	.375	.348	.292
.4	.527	.470	.412	.384	.330
.5	.560	.501	.445	.421	.368
.6	.591	.534	.481	.456	.403
.7	.619	.563	.513	.487	.434
.8	.646	.593	.541	.514	.463
.9	.673	.618	.571	.542	.490
1.0	.696	.643	.597	.567	.518
1.1	.719	.667	.620	.595	.540
1.2	.740	.689	.645	.619	.562
1.3	.760	.712	.664	.640	.582
1.4	.778	.730	.685	.660	.603
1.5	.796	.748	.706	.677	.624
1.6	.812	.766	.723	.693	.643
1.7	.826	.782	.740	.711	.660
1.8	.840	.798	.756	.729	.676
1.9	.853	.811	.771	.746	.688
2.0	.865	.825	.784	.759	.701
2.1	.877	.837	.797	.773	.721
2.2	.886	.849	.810	.787	.735
2.3	.895	.859	.820	.800	.749
2.4	.903	.871	.832	.811	.760
2.5	.910	.879	.841	.824	.769
2.6	.918	.887	.852	.834	.779
2.7	.925	.895	.861	.845	.789
2.8	.931	.903	.870	.853	.798
2.9	.936	.910	.878	.861	.805
3.0	.941	.917	.885	.869	.813
3.1	.946	.922	.891	.875	.821
3.2	.950	.928	.898	.883	.827
3.3	.955	.933	.904	.889	.834
3.4	.959	.938	.910	.895	.840
3.5	.962	.942	.916	.900	.847
3.6	.965	.947	.922	.906	.854
3.7	.968	.951	.927	.911	.861
3.8	.971	.954	.932	.917	.868

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

	n = 30 p = r/n = 15/30 γ = 0.50	γ = 0.75	γ = 0.90	γ = 0.95	γ = 0.99
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.974	.958	.936	.921	.873
4.0	.976	.961	.940	.926	.877
4.1	.978	.964	.943	.930	.883
4.2	.980	.966	.947	.934	.889
4.3	.981	.969	.950	.938	.895
4.4	.983	.971	.953	.942	.899
4.5	.984	.973	.956	.945	.904
4.6	.986	.975	.959	.949	.908
4.7	.987	.977	.961	.952	.912
4.8	.988	.979	.964	.954	.916
4.9	.989	.980	.966	.957	.920
5.0	.990	.982	.968	.959	.924

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

	n = 30	p = r/n = 22/30			
	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.382	.333	.281	.257	.206
.1	.416	.366	.318	.290	.243
.2	.453	.400	.353	.325	.277
.3	.489	.433	.385	.359	.307
.4	.521	.465	.419	.392	.341
.5	.553	.497	.449	.424	.373
.6	.583	.528	.479	.455	.406
.7	.612	.560	.512	.486	.438
.8	.640	.589	.540	.517	.465
.9	.666	.615	.566	.544	.486
1.0	.691	.641	.593	.569	.511
1.1	.716	.665	.618	.592	.534
1.2	.737	.687	.642	.615	.556
1.3	.758	.709	.664	.637	.577
1.4	.777	.729	.685	.659	.602
1.5	.795	.748	.705	.677	.623
1.6	.812	.766	.722	.697	.641
1.7	.827	.782	.741	.717	.656
1.8	.842	.798	.758	.734	.675
1.9	.855	.813	.774	.749	.692
2.0	.867	.826	.788	.765	.706
2.1	.878	.840	.803	.778	.718
2.2	.888	.852	.816	.793	.732
2.3	.897	.864	.828	.807	.746
2.4	.906	.875	.839	.818	.759
2.5	.914	.884	.851	.829	.771
2.6	.921	.894	.862	.839	.783
2.7	.928	.901	.871	.850	.795
2.8	.935	.909	.880	.859	.806
2.9	.940	.916	.888	.867	.816
3.0	.945	.923	.896	.876	.826
3.1	.950	.929	.902	.884	.836
3.2	.955	.934	.909	.891	.845
3.3	.958	.940	.915	.898	.853
3.4	.962	.944	.921	.905	.861
3.5	.966	.949	.927	.911	.868
3.6	.969	.953	.932	.917	.874
3.7	.971	.956	.937	.922	.881
3.8	.974	.960	.941	.927	.888

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 30$

$p = r/n = 22/30$

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.976	.963	.945	.931	.892
4.0	.979	.966	.948	.935	.897
4.1	.981	.969	.952	.939	.902
4.2	.982	.971	.956	.943	.907
4.3	.984	.973	.959	.947	.912
4.4	.985	.975	.961	.950	.916
4.5	.987	.977	.964	.953	.921
4.6	.988	.979	.967	.956	.926
4.7	.989	.981	.969	.959	.930
4.8	.990	.982	.971	.962	.934
4.9	.991	.984	.973	.964	.938
5.0	.992	.985	.975	.966	.942

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 30
p = r/n = 1

	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
.0	.376	.326	.283	.265	.222
.1	.413	.361	.317	.297	.255
.2	.450	.394	.349	.328	.286
.3	.483	.429	.381	.362	.317
.4	.516	.462	.413	.394	.350
.5	.550	.494	.446	.426	.380
.6	.580	.526	.478	.455	.409
.7	.610	.556	.507	.485	.436
.8	.638	.585	.536	.515	.463
.9	.665	.613	.565	.544	.490
1.0	.691	.639	.593	.570	.515
1.1	.715	.664	.618	.593	.543
1.2	.738	.688	.641	.618	.566
1.3	.759	.710	.665	.639	.587
1.4	.780	.730	.687	.662	.608
1.5	.798	.751	.708	.683	.629
1.6	.815	.770	.728	.703	.648
1.7	.830	.787	.746	.721	.667
1.8	.845	.803	.764	.739	.685
1.9	.858	.818	.781	.755	.706
2.0	.871	.832	.797	.772	.724
2.1	.882	.844	.811	.788	.741
2.2	.892	.857	.824	.802	.758
2.3	.902	.868	.836	.815	.773
2.4	.910	.879	.849	.827	.786
2.5	.919	.888	.860	.839	.797
2.6	.926	.897	.870	.851	.808
2.7	.933	.906	.879	.861	.819
2.8	.939	.913	.888	.870	.829
2.9	.944	.920	.897	.879	.838
3.0	.949	.926	.904	.887	.847
3.1	.954	.932	.911	.895	.858
3.2	.958	.938	.917	.903	.864
3.3	.962	.943	.923	.910	.873
3.4	.965	.948	.929	.916	.880
3.5	.968	.952	.934	.922	.888
3.6	.971	.956	.939	.927	.895
3.7	.974	.960	.943	.933	.902
3.8	.976	.963	.948	.938	.908

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 30$, $p = r/n = 1$	$\gamma = 0.50$	$\gamma = 0.75$	$\gamma = 0.90$	$\gamma = 0.95$	$\gamma = 0.99$
Z_a/Z_b	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$	$L^*(Z_a/Z_b)$
3.9	.978	.966	.952	.942	.914
4.0	.980	.969	.955	.946	.920
4.1	.982	.971	.958	.950	.925
4.2	.984	.974	.961	.954	.929
4.3	.985	.976	.964	.957	.934
4.4	.987	.978	.967	.960	.938
4.5	.988	.980	.969	.963	.942
4.6	.989	.981	.972	.966	.945
4.7	.990	.983	.974	.968	.949
4.8	.991	.984	.976	.971	.952
4.9	.992	.986	.978	.973	.955
5.0	.992	.987	.979	.975	.958

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

	$n = 50$, $p = r/n = 12/50$									
	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
.0	.441	.368	.320	.252	.207	.158	.163	.111	.080	.048
.1	.471	.405	.359	.292	.249	.197	.203	.147	.119	.073
.2	.504	.441	.397	.334	.292	.240	.246	.188	.155	.105
.3	.532	.477	.433	.375	.337	.284	.291	.231	.196	.144
.4	.560	.512	.467	.417	.380	.329	.335	.277	.240	.187
.5	.588	.545	.503	.458	.427	.375	.379	.324	.291	.233
.6	.614	.578	.537	.497	.469	.419	.419	.372	.350	.282
.7	.638	.609	.567	.535	.508	.463	.463	.418	.397	.332
.8	.664	.638	.600	.571	.545	.504	.505	.462	.454	.381
.9	.689	.666	.632	.605	.580	.543	.543	.505	.494	.428
1.0	.711	.692	.661	.636	.614	.580	.577	.544	.536	.478
1.1	.734	.717	.687	.666	.642	.614	.609	.581	.571	.514
1.2	.754	.740	.710	.693	.669	.645	.637	.614	.600	.552
1.3	.774	.761	.733	.718	.693	.674	.665	.645	.626	.586
1.4	.792	.781	.753	.741	.715	.700	.689	.673	.650	.617
1.5	.808	.800	.772	.762	.736	.723	.710	.698	.674	.644
1.6	.823	.817	.790	.781	.754	.744	.727	.720	.696	.669
1.7	.837	.833	.805	.799	.770	.764	.746	.740	.711	.691
1.8	.849	.848	.819	.815	.787	.781	.762	.758	.724	.710
1.9	.861	.861	.832	.830	.803	.797	.777	.775	.738	.727
2.0	.873	.873	.844	.844	.816	.811	.791	.789	.750	.742
2.1	.883	.885	.855	.856	.828	.825	.805	.803	.762	.756
2.2	.892	.895	.865	.867	.839	.837	.817	.815	.777	.769
2.3	.900	.905	.875	.878	.850	.848	.828	.827	.787	.780
2.4	.908	.913	.883	.887	.860	.858	.840	.837	.796	.791
2.5	.915	.921	.891	.896	.868	.867	.851	.847	.805	.800
2.6	.922	.928	.898	.904	.876	.876	.860	.856	.813	.809
2.7	.929	.935	.905	.912	.883	.884	.866	.864	.823	.817
2.8	.935	.941	.912	.919	.891	.892	.874	.872	.831	.825
2.9	.940	.946	.918	.925	.897	.899	.881	.879	.840	.832
3.0	.945	.951	.924	.931	.903	.905	.888	.886	.848	.839
3.1	.949	.956	.929	.936	.908	.911	.894	.892	.856	.846
3.2	.954	.960	.934	.941	.914	.917	.900	.898	.863	.852
3.3	.957	.964	.938	.946	.919	.922	.905	.904	.868	.868

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 50$
$p = r/n = 12/50$

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
3.4	.961	.967	.942	.950	.923	.927	.909	.909	.873	.863
3.5	.964	.970	.946	.954	.928	.932	.914	.914	.878	.868
3.6	.967	.973	.950	.957	.932	.936	.919	.919	.883	.873
3.7	.970	.976	.953	.961	.936	.940	.922	.923	.888	.878
3.8	.972	.978	.957	.964	.940	.944	.925	.927	.892	.882
3.9	.975	.980	.960	.967	.943	.947	.930	.931	.898	.887
4.0	.977	.982	.962	.969	.946	.951	.934	.935	.903	.891
4.1	.979	.984	.965	.972	.949	.954	.937	.938	.908	.895
4.2	.981	.985	.967	.974	.952	.957	.940	.942	.912	.899
4.3	.982	.987	.969	.976	.955	.959	.944	.945	.917	.902
4.4	.984	.988	.971	.978	.957	.962	.947	.948	.921	.906
4.5	.985	.989	.973	.980	.960	.964	.949	.951	.924	.909
4.6	.986	.990	.975	.981	.962	.967	.951	.953	.926	.913
4.7	.987	.991	.977	.983	.965	.969	.954	.956	.928	.916
4.8	.988	.992	.979	.984	.967	.971	.957	.958	.931	.919
4.9	.989	.993	.980	.985	.969	.973	.959	.960	.934	.922
5.0	.990	.993	.982	.988	.971	.974	.961	.962	.937	.924

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 50$

$p = r/n = 25/50$

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
.0	.383	.368	.333	.313	.286	.264	.258	.236	.209	.186
.1	.419	.405	.368	.351	.325	.303	.297	.275	.249	.224
.2	.456	.441	.406	.389	.363	.342	.336	.315	.288	.263
.3	.488	.477	.444	.427	.399	.382	.377	.354	.328	.303
.4	.522	.512	.477	.464	.436	.420	.414	.393	.368	.342
.5	.555	.545	.509	.499	.471	.457	.451	.430	.408	.381
.6	.586	.578	.543	.534	.507	.492	.483	.466	.441	.417
.7	.615	.600	.573	.566	.540	.526	.515	.500	.475	.452
.8	.643	.638	.603	.597	.569	.557	.546	.533	.502	.484
.9	.670	.666	.630	.626	.596	.587	.575	.563	.534	.515
1.0	.695	.692	.658	.653	.622	.615	.601	.591	.560	.544
1.1	.718	.717	.682	.679	.647	.641	.626	.618	.584	.570
1.2	.741	.740	.705	.703	.672	.666	.651	.642	.605	.595
1.3	.761	.761	.727	.725	.693	.689	.673	.666	.627	.618
1.4	.780	.781	.746	.746	.714	.710	.692	.687	.649	.640
1.5	.798	.800	.766	.766	.732	.730	.711	.707	.669	.660
1.6	.816	.817	.783	.784	.750	.749	.728	.726	.688	.679
1.7	.830	.833	.799	.800	.767	.767	.745	.744	.706	.697
1.8	.845	.848	.815	.816	.784	.783	.761	.761	.724	.714
1.9	.857	.801	.829	.831	.800	.798	.776	.776	.741	.729
2.0	.869	.873	.842	.844	.813	.812	.789	.791	.757	.744
2.1	.880	.885	.854	.856	.827	.825	.804	.804	.770	.758
2.2	.890	.895	.865	.868	.839	.838	.816	.817	.781	.771
2.3	.900	.905	.875	.878	.850	.849	.828	.829	.793	.784
2.4	.908	.913	.885	.888	.861	.860	.839	.840	.803	.796
2.5	.916	.921	.893	.897	.871	.870	.849	.850	.814	.807
2.6	.923	.928	.901	.906	.879	.879	.859	.860	.823	.817
2.7	.930	.935	.909	.913	.888	.888	.867	.869	.834	.827
2.8	.936	.941	.916	.920	.896	.896	.875	.878	.843	.836
2.9	.942	.946	.922	.927	.903	.903	.884	.886	.851	.845
3.0	.947	.951	.928	.933	.910	.910	.891	.893	.859	.854
3.1	.951	.956	.934	.938	.916	.917	.898	.900	.867	.862
3.2	.956	.960	.939	.943	.922	.923	.905	.907	.874	.869
3.3	.960	.964	.944	.948	.927	.928	.911	.913	.880	.876

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 50$
$p = r/n = 25/50$

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
3.4	.963	.967	.948	.952	.932	.933	.917	.919	.887	.883
3.5	.966	.970	.952	.956	.937	.938	.923	.924	.894	.889
3.6	.969	.973	.956	.960	.941	.943	.928	.929	.901	.895
3.7	.972	.976	.959	.963	.946	.947	.933	.934	.907	.901
3.8	.975	.978	.963	.966	.949	.951	.937	.938	.913	.907
3.9	.977	.980	.966	.969	.953	.954	.941	.942	.918	.912
4.0	.979	.982	.969	.972	.956	.958	.945	.946	.922	.917
4.1	.981	.984	.971	.974	.959	.961	.949	.950	.927	.921
4.2	.983	.985	.973	.976	.962	.964	.953	.953	.931	.925
4.3	.984	.987	.975	.978	.965	.966	.956	.956	.935	.930
4.4	.986	.988	.977	.980	.967	.969	.959	.959	.940	.933
4.5	.987	.989	.979	.982	.969	.971	.962	.962	.943	.937
4.6	.988	.990	.981	.983	.972	.973	.964	.965	.947	.941
4.7	.989	.991	.982	.985	.973	.975	.967	.967	.950	.944
4.8	.990	.992	.984	.986	.975	.977	.969	.969	.953	.947
4.9	.991	.993	.985	.987	.977	.979	.971	.971	.955	.950
5.0	.992	.993	.986	.988	.979	.980	.973	.973	.958	.953

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$
$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 50$

$p = r/n = 37/50$

Z_a/Z_b	$\gamma = 0.50$ $L^*(Z_a/Z_b)$	$\gamma = 0.50$ $L_A^*(Z_a/Z_b)$	$\gamma = 0.75$ $L^*(Z_a/Z_b)$	$\gamma = 0.75$ $L_A^*(Z_a/Z_b)$	$\gamma = 0.90$ $L^*(Z_a/Z_b)$	$\gamma = 0.90$ $L_A^*(Z_a/Z_b)$	$\gamma = 0.95$ $L^*(Z_a/Z_b)$	$\gamma = 0.95$ $L_A^*(Z_a/Z_b)$	$\gamma = 0.99$ $L^*(Z_a/Z_b)$	$\gamma = 0.99$ $L_A^*(Z_a/Z_b)$
.0	.377	.368	.335	.327	.304	.291	.283	.270	.252	.231
.1	.413	.405	.371	.364	.339	.327	.317	.305	.291	.265
.2	.448	.441	.406	.400	.373	.363	.352	.341	.328	.300
.3	.483	.477	.442	.436	.409	.399	.387	.376	.358	.334
.4	.517	.512	.477	.471	.441	.434	.422	.411	.389	.368
.5	.549	.545	.510	.505	.475	.467	.457	.444	.422	.401
.6	.580	.578	.542	.538	.506	.500	.489	.477	.452	.432
.7	.610	.609	.572	.569	.537	.531	.521	.508	.478	.463
.8	.639	.638	.601	.599	.567	.561	.548	.538	.506	.492
.9	.666	.666	.630	.627	.596	.590	.574	.566	.533	.520
1.0	.692	.692	.657	.654	.621	.617	.601	.593	.555	.546
1.1	.717	.717	.681	.679	.645	.642	.626	.619	.575	.572
1.2	.789	.740	.704	.703	.669	.666	.649	.643	.599	.596
1.3	.760	.761	.726	.725	.692	.689	.671	.666	.625	.619
1.4	.780	.781	.746	.746	.713	.711	.691	.688	.645	.641
1.5	.798	.800	.765	.766	.733	.731	.712	.708	.665	.661
1.6	.815	.817	.783	.784	.751	.750	.731	.727	.687	.681
1.7	.831	.833	.799	.801	.768	.768	.748	.746	.708	.699
1.8	.845	.848	.816	.817	.785	.784	.765	.763	.728	.717
1.9	.858	.861	.830	.831	.800	.800	.780	.779	.743	.734
2.0	.870	.873	.844	.845	.815	.814	.795	.794	.755	.750
2.1	.882	.885	.857	.857	.828	.828	.809	.808	.768	.764
2.2	.892	.895	.868	.869	.840	.841	.822	.821	.779	.779
2.3	.901	.905	.879	.880	.852	.852	.834	.833	.792	.792
2.4	.910	.913	.889	.890	.863	.863	.846	.845	.805	.804
2.5	.918	.921	.898	.899	.873	.874	.857	.856	.817	.816
2.6	.926	.928	.906	.907	.883	.883	.867	.866	.829	.828
2.7	.932	.935	.913	.915	.892	.892	.877	.875	.840	.838
2.8	.938	.941	.921	.922	.899	.900	.885	.884	.850	.848
2.9	.944	.946	.927	.929	.907	.908	.893	.892	.860	.857
3.0	.949	.951	.933	.935	.914	.915	.901	.900	.869	.866
3.1	.954	.956	.939	.940	.920	.921	.908	.907	.877	.875
3.2	.958	.960	.944	.945	.927	.927	.915	.914	.885	.882
3.3	.961	.964	.948	.950	.932	.933	.921	.920	.893	.890

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 50$

$p = r/n = 37/50$

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
3.4	.965	.967	.952	.954	.937	.938	.927	.926	.900	.897
3.5	.968	.970	.956	.958	.942	.943	.932	.931	.905	.903
3.6	.971	.973	.960	.962	.946	.947	.937	.936	.911	.909
3.7	.974	.976	.963	.965	.950	.951	.942	.941	.916	.915
3.8	.976	.978	.966	.968	.954	.955	.946	.945	.921	.920
3.9	.978	.980	.969	.971	.957	.958	.950	.949	.926	.925
4.0	.980	.982	.972	.973	.961	.962	.954	.953	.930	.930
4.1	.982	.984	.974	.975	.963	.965	.957	.956	.934	.934
4.2	.984	.985	.976	.977	.966	.967	.960	.959	.938	.939
4.3	.985	.987	.978	.979	.969	.970	.963	.962	.942	.942
4.4	.987	.988	.980	.981	.971	.972	.966	.965	.945	.946
4.5	.988	.989	.982	.983	.973	.974	.968	.968	.949	.950
4.6	.989	.990	.983	.984	.975	.976	.971	.970	.952	.953
4.7	.990	.991	.985	.986	.977	.978	.973	.972	.955	.956
4.8	.991	.992	.986	.987	.979	.980	.975	.974	.957	.959
4.9	.992	.993	.987	.988	.981	.981	.977	.976	.960	.961
5.0	.992	.993	.988	.989	.982	.983	.979	.978	.953	.964

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 50$

$p = r/n = 1$

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
.0	.372	.368	.336	.331	.304	.298	.284	.279	.263	.243
.1	.408	.405	.372	.367	.339	.333	.320	.312	.294	.275
.2	.444	.441	.408	.402	.374	.367	.356	.346	.325	.307
.3	.480	.477	.443	.438	.407	.402	.390	.380	.356	.339
.4	.514	.512	.477	.472	.442	.435	.422	.413	.388	.371
.5	.547	.545	.510	.506	.474	.468	.456	.446	.417	.403
.6	.579	.578	.542	.538	.506	.501	.487	.478	.448	.433
.7	.610	.609	.572	.569	.537	.532	.517	.508	.476	.464
.8	.639	.638	.603	.599	.586	.561	.548	.538	.507	.493
.9	.667	.666	.630	.627	.595	.590	.577	.567	.535	.521
1.0	.693	.692	.657	.654	.621	.617	.603	.594	.562	.548
1.1	.718	.717	.683	.680	.647	.643	.628	.620	.590	.574
1.2	.741	.740	.707	.704	.671	.668	.652	.645	.617	.599
1.3	.762	.761	.728	.726	.695	.691	.675	.669	.641	.623
1.4	.782	.781	.749	.747	.718	.713	.698	.691	.663	.646
1.5	.800	.800	.769	.767	.738	.734	.719	.712	.682	.668
1.6	.818	.817	.787	.786	.757	.753	.738	.732	.701	.689
1.7	.834	.833	.804	.803	.775	.772	.757	.751	.720	.708
1.8	.848	.848	.819	.819	.791	.789	.774	.769	.739	.727
1.9	.861	.861	.834	.833	.806	.804	.791	.785	.756	.744
2.0	.874	.873	.848	.847	.821	.819	.807	.801	.773	.761
2.1	.885	.885	.860	.860	.834	.833	.822	.815	.789	.776
2.2	.895	.895	.872	.871	.847	.846	.835	.828	.803	.791
2.3	.905	.905	.882	.882	.859	.858	.847	.841	.817	.805
2.4	.914	.913	.892	.892	.870	.869	.858	.853	.829	.818
2.5	.922	.921	.901	.901	.880	.879	.869	.864	.840	.830
2.6	.929	.928	.910	.910	.890	.889	.878	.874	.851	.842
2.7	.935	.935	.917	.917	.899	.897	.887	.883	.860	.852
2.8	.941	.941	.924	.924	.907	.905	.896	.892	.870	.862
2.9	.946	.946	.931	.931	.914	.913	.904	.900	.878	.872
3.0	.951	.951	.937	.937	.921	.920	.911	.908	.886	.881
3.1	.956	.956	.942	.942	.927	.926	.918	.915	.894	.889
3.2	.960	.960	.947	.947	.933	.932	.924	.921	.901	.897
3.3	.964	.964	.952	.952	.939	.938	.930	.927	.908	.904

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 50

p = r/n = 1

	γ = 0.50		γ = 0.75		γ = 0.90		γ = 0.95		γ = 0.99	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
3.4	.967	.967	.956	.956	.944	.943	.935	.933	.914	.910
3.5	.970	.970	.960	.960	.948	.947	.940	.938	.920	.917
3.6	.973	.973	.963	.963	.952	.952	.945	.943	.925	.922
3.7	.976	.976	.966	.966	.956	.956	.949	.947	.930	.928
3.8	.978	.978	.969	.969	.960	.959	.953	.951	.935	.933
3.9	.980	.980	.972	.972	.963	.962	.956	.955	.940	.938
4.0	.982	.982	.974	.975	.966	.965	.960	.959	.944	.942
4.1	.983	.984	.977	.977	.969	.968	.963	.962	.948	.946
4.2	.985	.985	.979	.979	.971	.971	.966	.965	.951	.950
4.3	.986	.987	.981	.981	.974	.973	.969	.968	.955	.954
4.4	.988	.988	.982	.982	.976	.975	.971	.970	.958	.957
4.5	.989	.989	.984	.984	.978	.977	.973	.972	.960	.960
4.6	.990	.990	.985	.985	.980	.979	.976	.975	.963	.963
4.7	.991	.991	.980	.987	.981	.981	.978	.977	.965	.965
4.8	.992	.992	.988	.988	.983	.983	.979	.978	.968	.968
4.9	.993	.993	.989	.989	.984	.984	.981	.980	.970	.970
5.0	.993	.993	.990	.990	.986	.985	.982	.982	.972	.972

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 100$

$p = r/n = 25/100$

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
.0	.402	.308	.315	.288	.243	.220	.193	.182	.119	.119
.1	.437	.405	.353	.328	.282	.261	.234	.222	.157	.156
.2	.469	.441	.390	.368	.325	.303	.280	.205	.198	.197
.3	.501	.477	.428	.409	.368	.346	.321	.309	.240	.241
.4	.534	.512	.466	.448	.408	.389	.863	.353	.284	.287
.5	.564	.545	.503	.487	.449	.431	.408	.397	.333	.384
.6	.593	.578	.538	.524	.487	.472	.451	.441	.384	.380
.7	.622	.609	.573	.559	.526	.512	.492	.483	.432	.426
.8	.648	.638	.605	.593	.562	.550	.533	.522	.484	.469
.9	.675	.636	.635	.625	.595	.585	.569	.560	.525	.511
1.0	.699	.692	.663	.655	.626	.618	.605	.595	.566	.550
1.1	.723	.717	.690	.682	.655	.649	.637	.628	.603	.585
1.2	.745	.740	.713	.708	.683	.677	.668	.657	.635	.618
1.3	.765	.761	.737	.732	.708	.703	.695	.685	.662	.648
1.4	.784	.781	.758	.754	.730	.727	.717	.710	.683	.675
1.5	.801	.800	.777	.774	.752	.749	.740	.732	.704	.699
1.6	.818	.817	.796	.793	.771	.768	.758	.753	.724	.721
1.7	.833	.833	.812	.810	.790	.787	.776	.772	.746	.741
1.8	.848	.848	.827	.825	.806	.803	.791	.789	.764	.759
1.9	.861	.861	.840	.840	.821	.818	.806	.804	.777	.775
2.0	.873	.873	.853	.853	.834	.832	.820	.818	.791	.790
2.1	.884	.885	.865	.865	.846	.845	.832	.831	.805	.803
2.2	.894	.893	.875	.876	.857	.856	.843	.843	.819	.815
2.3	.902	.905	.885	.886	.867	.867	.854	.854	.832	.827
2.4	.911	.913	.894	.896	.876	.877	.863	.864	.843	.837
2.5	.919	.921	.903	.904	.885	.886	.872	.874	.853	.847
2.6	.926	.928	.910	.912	.894	.894	.880	.882	.862	.856
2.7	.932	.935	.917	.919	.901	.902	.888	.890	.872	.864
2.8	.938	.941	.923	.926	.908	.909	.895	.898	.881	.872
2.9	.944	.946	.929	.932	.914	.916	.902	.905	.888	.879
3.0	.949	.951	.934	.938	.920	.922	.909	.911	.895	.886
3.1	.953	.956	.940	.943	.926	.928	.915	.917	.901	.892
3.2	.957	.960	.944	.948	.931	.933	.921	.923	.907	.899
3.3	.961	.964	.949	.952	.935	.938	.926	.928	.913	.904

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 100$
$p = r/n = 25/100$

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
3.4	.965	.967	.953	.956	.940	.942	.931	.933	.918	.909
3.5	.968	.970	.956	.959	.944	.947	.935	.937	.923	.914
3.6	.971	.973	.960	.963	.948	.950	.939	.941	.928	.919
3.7	.973	.976	.963	.966	.951	.954	.944	.945	.932	.924
3.8	.976	.978	.965	.969	.955	.957	.947	.949	.936	.928
3.9	.978	.980	.908	.971	.958	.960	.951	.952	.940	.932
4.0	.980	.982	.971	.974	.961	.963	.954	.955	.943	.935
4.1	.982	.984	.973	.976	.964	.966	.957	.958	.947	.939
4.2	.983	.985	.976	.978	.966	.968	.960	.961	.950	.942
4.3	.985	.987	.977	.980	.968	.971	.963	.964	.953	.945
4.4	.986	.988	.979	.981	.971	.973	.965	.966	.956	.948
4.5	.987	.989	.981	.983	.973	.975	.967	.968	.958	.951
4.6	.989	.990	.982	.984	.975	.977	.969	.970	.961	.954
4.7	.990	.991	.984	.986	.976	.978	.971	.972	.963	.956
4.8	.991	.992	.985	.987	.978	.980	.973	.974	.985	.959
4.9	.991	.993	.986	.988	.979	.981	.975	.976	.967	.961
5.0	.992	.993	.987	.989	.981	.983	.977	.978	.969	.963

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 100$
$p = r/n = 50/100$

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
.0	.377	.368	.339	.329	.309	.294	.287	.273	.244	.236
.1	.413	.405	.377	.367	.348	.333	.323	.312	.284	.275
.2	.448	.441	.413	.405	.386	.371	.361	.352	.318	.315
.3	.483	.477	.450	.442	.422	.410	.400	.390	.359	.354
.4	.516	.512	.486	.478	.458	.447	.439	.428	.399	.393
.5	.549	.545	.522	.513	.493	.483	.476	.465	.441	.430
.6	.581	.578	.555	.547	.525	.518	.510	.500	.477	.466
.7	.612	.609	.586	.579	.557	.551	.542	.534	.511	.500
.8	.640	.638	.615	.609	.587	.582	.571	.565	.540	.533
.9	.668	.666	.643	.638	.617	.611	.598	.595	.567	.563
1.0	.694	.692	.669	.665	.644	.639	.626	.623	.595	.591
1.1	.718	.717	.695	.690	.669	.665	.652	.649	.621	.618
1.2	.741	.740	.717	.714	.691	.689	.676	.673	.644	.642
1.3	.761	.761	.738	.736	.713	.712	.698	.696	.667	.666
1.4	.781	.781	.759	.757	.734	.733	.720	.718	.687	.687
1.5	.798	.800	.777	.776	.753	.753	.739	.738	.707	.707
1.6	.816	.817	.794	.794	.771	.771	.756	.756	.726	.726
1.7	.831	.833	.810	.811	.788	.788	.773	.774	.745	.744
1.8	.846	.848	.825	.826	.804	.804	.790	.790	.762	.761
1.9	.859	.861	.840	.840	.818	.819	.804	.805	.776	.776
2.0	.872	.873	.852	.853	.832	.832	.818	.819	.792	.791
2.1	.883	.885	.864	.865	.845	.845	.832	.832	.805	.804
2.2	.893	.895	.875	.876	.857	.857	.844	.844	.818	.817
2.3	.903	.905	.885	.887	.867	.868	.855	.855	.830	.829
2.4	.912	.913	.894	.896	.877	.878	.866	.866	.842	.840
2.5	.919	.921	.903	.905	.887	.887	.875	.876	.851	.850
2.6	.927	.928	.911	.913	.895	.896	.884	.885	.861	.860
2.7	.933	.935	.918	.920	.903	.904	.892	.893	.870	.869
2.8	.939	.941	.925	.927	.910	.912	.900	.901	.879	.878
2.9	.944	.946	.931	.933	.917	.919	.907	.908	.887	.886
3.0	.949	.951	.937	.939	.923	.925	.914	.915	.894	.893
3.1	.954	.956	.942	.944	.929	.931	.919	.921	.902	.900
3.2	.958	.960	.947	.949	.934	.936	.925	.927	.908	.907
3.3	.962	.964	.952	.953	.940	.941	.931	.933	.915	.913

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 100$

$p = r/n = 50/100$

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
3.4	.966	.967	.956	.957	.944	.946	.936	.938	.921	.919
3.5	.969	.970	.959	.961	.949	.950	.941	.942	.926	.924
3.6	.972	.973	.963	.964	.953	.954	.945	.947	.932	.929
3.7	.974	.976	.966	.967	.956	.958	.949	.951	.937	.934
3.8	.977	.978	.968	.970	.960	.961	.953	.954	.941	.938
3.9	.979	.980	.971	.973	.963	.964	.957	.958	.945	.942
4.0	.981	.982	.974	.975	.966	.967	.960	.961	.948	.946
4.1	.982	.984	.976	.977	.968	.970	.963	.964	.952	.950
4.2	.984	.985	.978	.979	.971	.972	.966	.966	.955	.953
4.3	.986	.987	.980	.981	.973	.974	.968	.969	.958	.956
4.4	.987	.988	.981	.983	.975	.976	.971	.971	.961	.959
4.5	.988	.989	.983	.984	.977	.978	.973	.973	.964	.962
4.6	.989	.990	.984	.986	.979	.980	.975	.975	.966	.965
4.7	.990	.991	.986	.987	.981	.981	.977	.977	.968	.967
4.8	.991	.992	.987	.988	.982	.983	.979	.979	.971	.969
4.9	.992	.993	.988	.989	.983	.984	.980	.981	.973	.971
5.0	.993	.993	.989	.990	.985	.986	.982	.982	.975	.973

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 100

p = r/n = 75/100

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
.0	.374	.368	.347	.339	.320	.314	.305	.298	.273	.270
.1	.410	.405	.383	.376	.357	.350	.341	.335	.307	.306
.2	.445	.441	.419	.412	.393	.386	.377	.371	.343	.342
.3	.480	.477	.455	.448	.427	.422	.414	.406	.383	.377
.4	.515	.512	.489	.483	.461	.457	.448	.441	.421	.411
.5	.548	.545	.523	.517	.494	.491	.481	.475	.452	.445
.6	.579	.578	.555	.550	.526	.523	.513	.508	.482	.477
.7	.609	.609	.585	.581	.557	.555	.543	.539	.513	.508
.8	.639	.638	.613	.611	.587	.585	.572	.569	.541	.538
.9	.666	.666	.641	.639	.615	.613	.599	.597	.568	.566
1.0	.692	.692	.668	.665	.642	.640	.625	.624	.594	.593
1.1	.716	.717	.692	.691	.666	.665	.650	.650	.619	.619
1.2	.739	.740	.715	.714	.690	.689	.675	.674	.642	.643
1.3	.761	.761	.737	.736	.712	.712	.695	.696	.666	.666
1.4	.780	.781	.758	.757	.732	.733	.718	.718	.688	.688
1.5	.798	.800	.777	.776	.753	.753	.738	.738	.709	.708
1.6	.816	.817	.794	.794	.771	.772	.757	.757	.728	.727
1.7	.831	.833	.811	.811	.788	.789	.775	.775	.747	.746
1.8	.846	.848	.826	.826	.804	.805	.790	.791	.764	.763
1.9	.859	.861	.840	.841	.819	.820	.807	.806	.779	.779
2.0	.872	.873	.853	.854	.833	.834	.821	.821	.793	.794
2.1	.883	.885	.865	.866	.846	.847	.834	.834	.808	.808
2.2	.893	.895	.876	.877	.858	.859	.847	.847	.821	.821
2.3	.903	.905	.887	.888	.809	.870	.858	.858	.835	.834
2.4	.911	.913	.896	.897	.880	.880	.868	.869	.846	.845
2.5	.919	.921	.905	.906	.889	.890	.878	.879	.856	.856
2.6	.927	.928	.913	.914	.898	.899	.887	.888	.885	.866
2.7	.933	.935	.920	.921	.906	.907	.896	.897	.875	.876
2.8	.939	.941	.927	.928	.913	.914	.904	.905	.885	.884
2.9	.945	.946	.933	.934	.920	.921	.911	.912	.894	.893
3.0	.950	.951	.939	.940	.927	.928	.918	.919	.902	.900
3.1	.956	.956	.944	.945	.932	.934	.924	.925	.910	.907
3.2	.959	.960	.949	.950	.938	.939	.929	.931	.916	.914
3.3	.962	.964	.953	.954	.943	.944	.935	.937	.922	.920

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 100$

$p = r/n = 75/100$

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
3.4	.966	.967	.957	.958	.947	.949	.940	.942	.928	.926
3.5	.969	970	.961	.962	.952	.953	.944	.946	.933	.931
3.6	.972	.973	.964	.965	.955	.957	.949	.950	.938	.936
3.7	.975	.976	.967	.968	.959	.960	.953	.954	.942	.941
3.8	.977	.978	.970	.971	.962	.963	.957	.958	.946	.945
3.9	.979	.980	.973	.974	.965	.966	.960	.961	.950	.949
4.0	.981	.982	.975	.976	.968	.969	.963	.964	.954	.953
4.1	.983	.984	.977	.978	.971	.972	.966	.967	.957	.956
4.2	.984	.985	.979	.980	.973	.974	.969	.970	.960	.959
4.3	.986	.987	.981	.982	.975	.976	.971	.972	.963	.962
4.4	.987	.988	.983	.983	.977	.978	.978	.974	.966	.965
4.5	.988	.989	.984	.985	.979	.980	.975	.976	.968	.968
4.6	.989	.990	.986	.986	.981	.982	.977	.978	.971	.970
4.7	.990	.991	.987	.987	.983	.983	.979	.980	.973	.972
4.8	.991	.992	.988	.989	.984	.985	.981	.982	.975	.974
4.9	.992	.993	.989	.990	.985	.986	.982	.983	.976	.976
5.0	.993	.993	.990	.991	.987	.987	.984	.984	.978	.978

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 100$
$p = r/n = 1$

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
.0	.371	.368	.347	.342	.325	.318	.304	.304	.282	.279
.1	.408	.405	.382	.378	.361	.354	.340	.339	.314	.312
.2	.445	.441	.419	.414	.394	.389	.377	.374	.348	.346
.3	.480	.477	.455	.449	.428	.424	.412	.409	.381	.380
.4	.514	.512	.489	.481	.461	.458	.447	.443	.415	.413
.5	.547	.545	.522	.517	.494	.492	.479	.476	.448	.446
.6	.579	.578	.554	.550	.526	.524	.512	.508	.481	.478
.7	.610	.609	.585	.581	.558	.555	.544	.539	.510	.508
.8	.639	.638	.614	.611	.587	.585	.572	.569	.543	.538
.9	.666	.666	.642	.639	.615	.613	.601	.598	.573	.567
1.0	.693	.692	.669	.666	.642	.641	.629	.625	.602	.594
1.1	.717	.717	.694	.691	.667	.666	.653	.651	.626	.620
1.2	.741	.740	.718	.715	.692	.690	.677	.675	.650	.645
1.3	.762	.761	.740	.737	.715	.713	.700	.698	.672	.669
1.4	.782	.781	.760	.758	.736	.735	.721	.720	.693	.691
1.5	.800	.800	.779	.777	.756	.755	.742	.741	.713	.712
1.6	.817	.817	.797	.795	.774	.774	.761	.760	.732	.732
1.7	.833	.833	.814	.812	.792	.791	.779	.778	.750	.751
1.8	.848	.848	.829	.828	.808	.808	.795	.795	.767	.769
1.9	.861	.861	.843	.842	.823	.823	.810	.810	.784	.785
2.0	.873	.873	.856	.855	.837	.837	.824	.825	.799	.801
2.1	.885	.885	.868	.868	.850	.850	.837	.839	.813	.815
2.2	.895	.895	.879	.879	.862	.862	.850	.851	.827	.828
2.3	.905	.905	.890	.889	.873	.873	.862	.863	.840	.841
2.4	.913	.913	.899	.899	.884	.884	.873	.874	.852	.853
2.5	.921	.921	.908	.907	.893	.893	.883	.884	.862	.864
2.6	.929	.928	.916	.916	.902	.902	.892	.893	.871	.874
2.7	.935	.935	.923	.923	.910	.910	.901	.902	.881	.883
2.8	.941	.941	.930	.930	.918	.918	.909	.909	.889	.892
2.9	.946	.946	.936	.936	.925	.924	.916	.917	.898	.900
3.0	.951	.951	.942	.941	.931	.931	.923	.924	.905	.908
3.1	.956	.956	.947	.947	.937	.937	.929	.930	.912	.915
3.2	.960	.960	.952	.951	.942	.942	.935	.935	.919	.921
3.3	.964	.964	.956	.956	.947	.947	.941	.941	.925	.927

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 100$

$p = r/n = 1$

	$\gamma = 0.50$		$\gamma = 0.75$		$\gamma = 0.90$		$\gamma = 0.95$		$\gamma = 0.99$	
$\frac{Z_a}{Z_b}$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$	$L^*\left(\frac{Z_a}{Z_b}\right)$	$L_A^*\left(\frac{Z_a}{Z_b}\right)$
3.4	.967	.967	.960	.960	.951	.951	.945	.946	.931	.933
3.5	.970	.970	.963	.963	.955	.955	.950	.950	.936	.938
3.6	.973	.973	.966	.966	.959	.959	.954	.954	.941	.943
3.7	.976	.976	.969	.969	.963	.963	.958	.958	.945	.947
3.8	.978	.978	.972	.972	.966	.966	.961	.961	.950	.951
3.9	.980	.980	.975	.975	.969	.969	.964	.965	.953	.955
4.0	.982	.982	.977	.977	.972	.971	.967	.967	.957	.959
4.1	.984	.984	.979	.979	.974	.974	.970	.970	.960	.962
4.2	.985	.985	.981	.981	.976	.976	.972	.973	.963	.965
4.3	.987	.987	.983	.983	.978	.978	.974	.975	.966	.968
4.4	.988	.988	.984	.984	.980	.980	.977	.977	.969	.970
4.5	.989	.989	.986	.986	.982	.982	.979	.979	.971	.972
4.6	.990	.990	.987	.987	.983	.983	.980	.981	.973	.975
4.7	.991	.991	.988	.988	.985	.985	.982	.982	.975	.977
4.8	.992	.992	.989	.989	.986	.986	.983	.984	.977	.978
4.9	.993	.993	.990	.990	.987	.987	.985	.985	.979	.980
5.0	.993	.993	.991	.991	.988	.988	.986	.986	.981	.982

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE IX. FACTORS FOR TESTS FOR INCREASING HAZARD RATES

N/γ	0.02	0.05	0.10	0.25	0.40
5	1.656	1.464	1.305	1.052	0.896
6	1.605	1.435	1.285	1.067	0.926
7	1.565	1.410	1.274	1.075	0.944
8	1.531	1.389	1.263	1.080	0.957
9	1.504	1.372	1.255	1.081	0.966
10	1.479	1.355	1.247	1.082	0.973
11	1.458	1.342	1.239	1.082	0.978
12	1.439	1.330	1.233	1.082	0.983
13	1.422	1.318	1.227	1.082	0.986
14	1.408	1.309	1.221	1.081	0.989
15	1.397	1.299	1.215	1.081	0.992
16	1.383	1.290	1.211	1.080	0.994
17	1.374	1.284	1.206	1.079	0.996
18	1.362	1.276	1.202	1.079	0.997
19	1.353	1.269	1.198	1.078	0.999
20	1.346	1.264	1.193	1.076	1.000
22	1.330	1.253	1.186	1.075	1.002
24	1.318	1.242	1.179	1.073	1.003
26	1.305	1.234	1.174	1.072	1.005
28	1.295	1.227	1.168	1.071	1.006
30	1.285	1.220	1.163	1.070	1.007
32	1.277	1.214	1.159	1.067	1.007
34	1.269	1.208	1.155	1.066	1.008
36	1.261	1.202	1.151	1.065	1.008
38	1.255	1.198	1.147	1.064	1.009
40	1.248	1.192	1.143	1.064	1.009
42	1.244	1.188	1.140	1.063	1.010
44	1.238	1.183	1.136	1.062	1.010
46	1.233	1.181	1.134	1.060	1.010
48	1.228	1.176	1.131	1.059	1.010
50	1.224	1.174	1.129	1.059	1.011
52	1.220	1.171	1.126	1.058	1.011
54	1.216	1.167	1.124	1.057	1.011
56	1.212	1.164	1.122	1.057	1.011
58	1.209	1.161	1.120	1.056	1.011
60	1.205	1.159	1.118	1.055	1.011
62	1.202	1.157	1.116	1.055	1.011
64	1.199	1.155	1.115	1.054	1.011
66	1.196	1.152	1.112	1.054	1.012
68	1.193	1.151	1.111	1.053	1.012
70	1.190	1.148	1.110	1.053	1.012
72	1.189	1.147	1.107	1.052	1.012
74	1.186	1.144	1.106	1.052	1.012
76	1.183	1.143	1.105	1.050	1.012
78	1.182	1.142	1.104	1.050	1.012
80	1.179	1.139	1.102	1.050	1.012
90	1.170	1.132	1.096	1.048	1.012
100	1.161	1.126	1.092	1.046	1.012
110	1.155	1.120	1.087	1.044	1.012
120	1.148	1.115	1.083	1.043	1.012

TABLE IX. FACTORS FOR TESTS FOR INCREASING HAZARD RATES (Continued)

N/γ	0.50	0.60	0.70	0.75	0.80
5	0.808	0.726	0.642	0.598	0.552
6	0.842	0.767	0.688	0.648	0.602
7	0.866	0.796	0.722	0.684	0.641
8	0.884	0.818	0.747	0.712	0.671
9	0.898	0.835	0.767	0.735	0.695
10	0.908	0.848	0.784	0.753	0.715
11	0.917	0.860	0.798	0.768	0.732
12	0.924	0.869	0.810	0.781	0.746
13	0.930	0.877	0.820	0.792	0.758
14	0.935	0.883	0.829	0.801	0.769
15	0.940	0.890	0.837	0.810	0.779
16	0.944	0.895	0.844	0.818	0.787
17	0.947	0.900	0.850	0.824	0.795
18	0.950	0.904	0.856	0.830	0.802
19	0.953	0.908	0.860	0.836	0.808
20	0.955	0.912	0.866	0.842	0.814
22	0.960	0.917	0.874	0.850	0.824
24	0.963	0.922	0.881	0.858	0.833
26	0.966	0.927	0.886	0.865	0.841
28	0.968	0.931	0.892	0.871	0.847
30	0.971	0.934	0.897	0.876	0.854
32	0.973	0.937	0.901	0.881	0.859
34	0.974	0.940	0.905	0.886	0.864
36	0.976	0.942	0.908	0.889	0.869
38	0.976	0.944	0.912	0.893	0.873
40	0.978	0.947	0.914	0.896	0.876
42	0.978	0.949	0.916	0.899	0.880
44	0.979	0.950	0.919	0.902	0.883
46	0.980	0.951	0.922	0.904	0.886
48	0.981	0.953	0.923	0.907	0.889
50	0.982	0.954	0.925	0.909	0.891
52	0.983	0.956	0.928	0.911	0.894
54	0.983	0.957	0.929	0.913	0.896
56	0.984	0.958	0.930	0.915	0.898
58	0.985	0.959	0.932	0.916	0.900
60	0.985	0.961	0.934	0.918	0.902
62	0.986	0.962	0.934	0.920	0.904
64	0.986	0.962	0.936	0.921	0.906
66	0.986	0.962	0.937	0.922	0.907
68	0.987	0.963	0.938	0.923	0.909
70	0.987	0.964	0.940	0.925	0.911
72	0.988	0.965	0.941	0.926	0.912
74	0.988	0.965	0.942	0.928	0.913
76	0.988	0.966	0.942	0.928	0.915
78	0.989	0.967	0.943	0.929	0.916
80	0.989	0.967	0.944	0.930	0.917
90	0.990	0.970	0.948	0.935	0.922
100	0.991	0.972	0.951	0.939	0.927
110	0.992	0.974	0.954	0.942	0.931
120	0.993	0.976	0.956	0.945	0.934

TABLE IX. FACTORS FOR TESTS FOR INCREASING HAZARD RATES (Continued)

N/γ	0.85	0.90	0.95	0.98
5	0.500	0.439	0.360	0.284
6	0.552	0.493	0.410	0.326
7	0.592	0.537	0.458	0.379
8	0.624	0.572	0.496	0.421
9	0.650	0.601	0.527	0.455
10	0.672	0.624	0.553	0.483
11	0.690	0.644	0.575	0.507
12	0.705	0.661	0.594	0.528
13	0.719	0.676	0.611	0.546
14	0.730	0.689	0.626	0.563
15	0.741	0.701	0.639	0.577
16	0.751	0.711	0.651	0.591
17	0.759	0.720	0.662	0.602
18	0.767	0.729	0.672	0.613
19	0.774	0.737	0.682	0.624
20	0.781	0.745	0.690	0.633
22	0.792	0.758	0.705	0.650
24	0.802	0.769	0.718	0.665
26	0.812	0.779	0.730	0.678
28	0.820	0.788	0.740	0.690
30	0.826	0.796	0.750	0.700
32	0.833	0.802	0.758	0.710
34	0.838	0.809	0.766	0.718
36	0.843	0.815	0.773	0.726
38	0.848	0.820	0.779	0.734
40	0.852	0.826	0.786	0.740
42	0.857	0.830	0.790	0.747
44	0.860	0.835	0.796	0.752
46	0.864	0.839	0.801	0.758
48	0.867	0.842	0.805	0.763
50	0.870	0.846	0.810	0.769
52	0.873	0.850	0.814	0.773
54	0.876	0.852	0.817	0.778
56	0.878	0.855	0.821	0.781
58	0.881	0.858	0.824	0.786
60	0.883	0.860	0.828	0.789
62	0.885	0.864	0.830	0.792
64	0.887	0.866	0.833	0.796
66	0.889	0.868	0.836	0.799
68	0.891	0.870	0.839	0.802
70	0.893	0.873	0.842	0.805
72	0.894	0.874	0.844	0.808
74	0.896	0.876	0.846	0.811
76	0.898	0.878	0.848	0.814
78	0.899	0.880	0.850	0.816
80	0.901	0.882	0.852	0.818
90	0.907	0.890	0.862	0.829
100	0.912	0.896	0.870	0.839
110	0.917	0.901	0.876	0.847
120	0.921	0.906	0.883	0.854

*TABLE X. PROBABILITY OF OBTAINING A PERMUTATION WITH $T \leq \overline{T}$ IN PERMUTATIONS OF n VARIABLES**

n \ T	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
3	165	500	833																			
4	042	167	375	625	833	958																
5	008	042	117	242	408	592	758	883	958	992												
6	001	008	028	068	136	235	360	500	500	640	765	864	932	972	992	999						
7	000	001	005	015	035	068	119	191	281	386	500	500	614	719	809	881	932	965	985	995	999	
8	000	000	001	003	007	016	031	054	089	138	199	274	360	452								
9	000	000	000	000	001	003	006	012	022	038	060	090	130	179	238	306	381	460				
10	000	000	000	000	000	000	001	002	005	008	014	023	036	054	078	108	146	190	242	300	364	431
P(c)	000	000	000	000	001	001	002	004	006	010	016	025	037	054	076	105	142	186	237	296	360	429

*Tabular values should be divided by 1000.

$$P(c) = \frac{1}{\sqrt{2\pi}} \int_{\infty}^{-c} e^{-x^2/2} dx, \quad c = \left(\frac{n(n-1)}{4} - T - \frac{1}{2}\right) \Big/ \sqrt{\frac{2n^2 + 3n^2 - 5n}{72}}, \quad n > 10.$$

**Reproduced from "Nonparametric Tests Against Trends," by H. B. Mann, Econometrica, Vol. 13 (1945) pp. 245-259.

TABLE XI. UNBIASING FACTORS FOR THE M.L.E. OF C

n	5	6	7	8	9	10	11	12	13	14	15	16
B(n)	.669	.752	.792	.820	.842	.859	.872	.883	.893	.901	.908	.914
n	18	20	22	24	26	28	30	32	34	36	38	40
B(n)	.923	.931	.938	.943	.947	.951	.955	.958	.960	.962	.964	.966
n	42	44	46	48	50	52	54	56	58	60	62	64
B(n)	.968	.970	.971	.972	.973	.974	.975	.976	.977	.978	.979	.980
n	66	68	70	72	74	76	78	80	85	90	100	120
B(n)	.980	.981	.981	.982	.982	.983	.983	.984	.985	.986	.987	.990

This table is reproduced from "Inferences on the Parameters of the Weibull Distribution" by D. R. Thoman, L. J. Bain, and C. E. Antle, Techometrics, Vol. 11, No. 3, August 1969, pp. 445-460.

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